Table B.5-7. Analysis of covariance of active chlorophyll a with station and preoperational-operational treatments.

Source of Variation	Degrees Freedom	Sums of Squares	Mean Square	F-Ratio
Stations	6	166.44	27.74	0.73
Operational Period	1	227.38	227.38	5.98*
Interaction	6	127.54	21.26	0.56
Covariates	4	1858.90	464.73	12.22**
sin $(2\pi t/365)$	1	638.17	638.17	16.78**
sin $(4\pi t/365)$	1	446.01	446.01	11.73**
cos $(6\pi t/365)$	1	994.28	994.28	26.14**
cos $(8\pi t/365)$	1	302.07	302.07	7.94*
Error	389	14795.92	38.04	
Total	406	17176.18		

*Significant at $p < 0.05$.

**Significant at $p < 0.01$.

Table B.5-8. Seasonally adjusted station-treatment means of active chlorophyll a.

Year	1A	2A	3A	1B	2B	3B	2C	Mean
71	18.3	22.3	22.3	21.3	17.6	19.0	16.9	19.7
72	9.5	10.1	11.7	9.8	11.9	11.5	10.2	10.7
73	19.9	14.4	16.4	18.7	15.9	16.7	13.7	16.5
74	11.4	8.1	8.7	10.3	10.1	10.4	9.2	9.7
75	7.5	6.5	7.3	8.5	5.8	4.2	5.7	6.5
76	15.3	11.1	16.2	12.9	16.0	14.1	14.6	14.3
77	13.2	16.3	10.8	14.4	10.9	10.6	11.3	12.5
78	10.3	10.0	9.5	9.8	8.2	9.0	10.0	9.5
	13.2	12.4	12.9	13.2	12.1	11.9	11.5	12.4

Units Operational

0	14.5	12.1	13.8	14.1	13.1	13.6	11.4	13.2
1	12.9	13.5	13.3	12.6	12.5	10.6	11.5	11.1
2	11.5	11.8	8.9	12.7	9.3	10.1	10.6	10.7
	13.0	12.5	12.0	13.1	11.6	11.4	11.2	11.7

Operational Period

Preop.	14.5	12.1	13.8	14.1	13.1	17.6	11.4	13.8
Op.	12.2	12.6	11.0	12.6	10.8	10.3	11.0	11.5
	13.4	12.4	12.4	13.4	12.0	14.0	11.2	12.7

Table B.5-9. Analysis of covariance of carbon-14 productivity with station and year treatments.

Source of Variation	Degrees Freedom	Sums of Squares	Mean Square	F-Ratio
Stations	6	4475.43	745.90	0.91
Years	7	81190.30	11598.61	14.12**
Interaction	42	18661.96	444.33	0.54
Covariates	5	347912.50	69582.50	84.71**
sin (2πt/365)	1	231108.60	231108.60	281.35**
cos (2πt/365)	1	163350.19	163350.19	198.86**
sin (4πt/365)	1	21202.85	21202.85	25.81**
cos (4πt/365)	1	5457.03	5457.03	6.64*
sin (6πt/365)	1	9014.43	9014.43	10.97**
Error	459	337039.31	821.44	
Total	519	829279.50		

*Significant at $p < 0.05$.

**Significant at $p < 0.01$.

Table B.5-10. Analysis of covariance of carbon-14 productivity with station and generating-unit treatments.

Source of Variation	Degrees Freedom	Sums of Squares	Mean Square	F-Ratio
Stations	6	5,113.99	852.33	0.99
Units Operational	2	55,913.20	27,956.60	32.59**
Interaction	12	2,642.71	220.23	0.26
Covariates	4	403,365.34	100,841.34	117.54**
sin $(2\pi t/365)$	1	272,900.23	272,900.23	318.08**
cos $(2\pi t/365)$	1	198,248.19	198,248.19	231.07**
sin $(4\pi t/365$	1	22,361.18	22,361.18	26.06**
sin $(6\pi t/365)$	1	20,619.72	20,619.72	24.03**
Error	493	422,968.89	857.95	
Total	519	890,007.13		

**Significant at $p < 0.01$.

Table B.5-11. Analysis of covariance of carbon-14 productivity with station and preoperational-operational treatments.

Source of Variation	Degrees Freedom	Sums of Squares	Mean Square	F-Ratio
Stations	6	9226.15	1537.69	1.79
Operational Period	1	49277.57	49277.57	57.46**
Interaction	6	1142.55	190.43	0.22
Covariates	4	412996.77	10324.29	12.04**
sin $(2\pi t/365)$	1	272659.73	272659.73	317.92**
cos $(2\pi t/365)$	1	195953.63	195953.63	228.48**
sin $(4\pi t/365)$	1	21203.38	21203.38	24.72**
sin $(6\pi t/365)$	1	20408.56	20408.56	23.80**
Error	502	430538.18	857.65	
Total	519	526881.22		

**Significant at $p < 0.05$.

Table B.5-12. Seasonally adjusted station-treatment means of carbon-14 productivity.

Year	1A	2A	3A	1B	2B	3B	2C	Mean
71	62.4	78.5	73.3	68.6	63.2	77.8	72.0	70.8
72	37.8	47.1	46.3	42.7	46.9	38.2	34.0	41.9
73	49.7	42.4	76.2	74.4	53.1	62.2	63.5	60.2
74	48.0	53.0	52.3	38.5	49.1	38.2	43.3	46.0
75	26.8	26.5	43.3	39.3	27.3	30.5	31.5	32.2
76	25.5	33.7	48.6	31.4	31.9	41.9	30.1	34.7
77	28.1	28.8	21.7	19.7	17.8	23.8	16.0	22.3
78	40.3	47.7	42.7	38.6	38.6	38.2	36.2	40.3
	39.8	44.7	50.6	44.2	41.0	43.9	40.8	43.6

Units Operational	1A	2A	3A	1B	2B	3B	2C	Mean
0	45.7	49.0	60.2	54.7	49.8	49.5	49.1	51.1
1	28.5	34.4	46.7	35.5	30.0	37.9	32.3	35.0
2	26.2	27.0	25.2	22.6	20.9	25.9	16.9	23.5
	33.5	36.8	37.6	37.6	33.6	37.8	32.8	36.5

Operational Period	1A	2A	3A	1B	2B	3B	2C	Mean
Preop.	45.6	49.0	60.2	54.7	49.8	49.4	49.1	51.1
Op.	27.8	31.6	39.9	30.7	26.6	33.7	26.2	30.8
	36.7	40.3	50.1	42.7	38.2	41.6	37.7	41.0

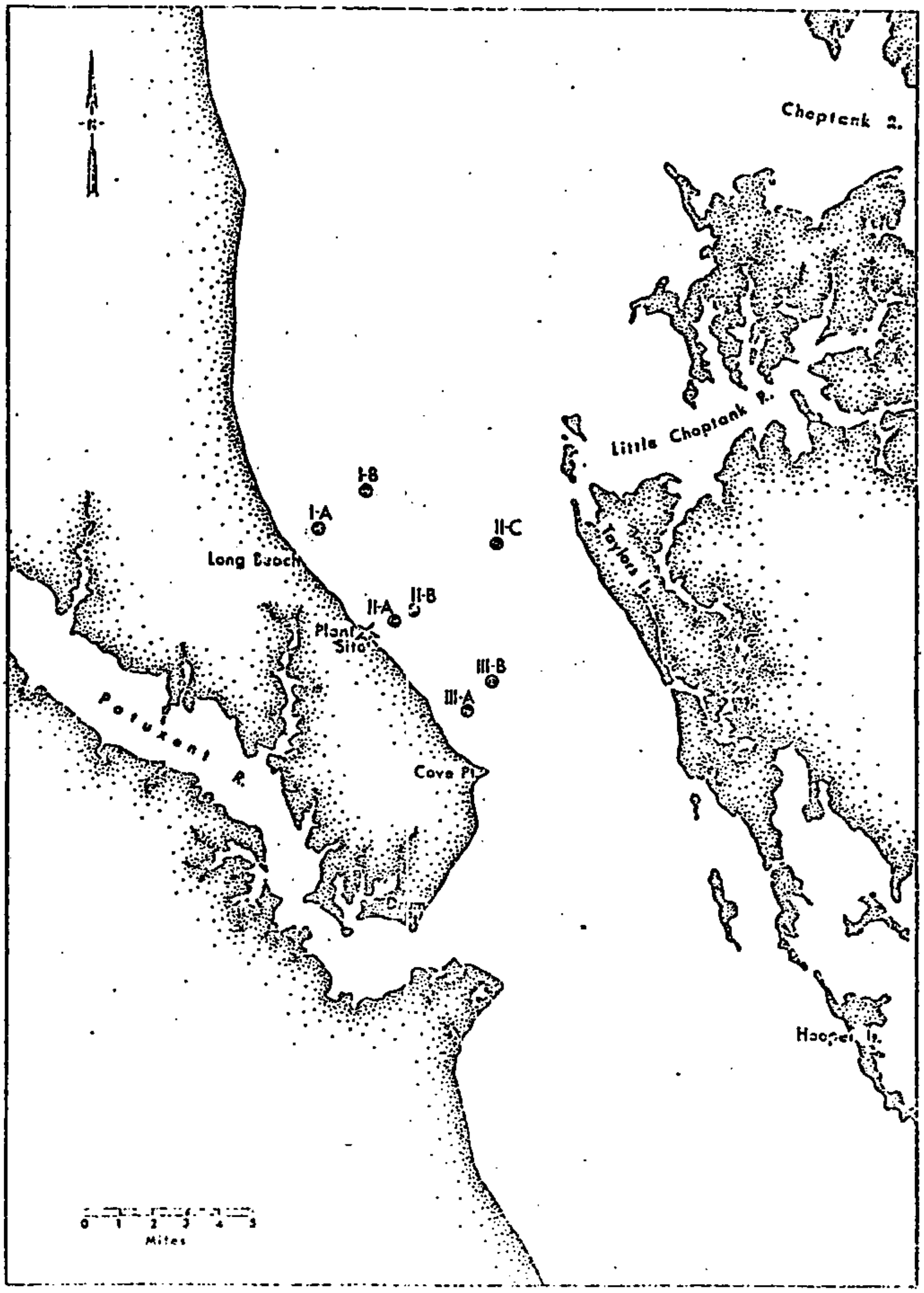

Figure B.5-1. Sampling stations at Calvert Cliffs (from Ref. 117).

APPENDIX B.6. - PHYTOPLANKTON PRODUCTIVITY STUDIES IN THE CALVERT CLIFFS AREA, AUGUST 1971 THROUGH DECEMBER 1972

(ANSP)

B.6.1. Objective

To evaluate several approaches to monitoring the effect of plant operations on phytoplankton biomass and productivity.

B.6.2. Data Source

Ref. 30.

B.6.3. Study History

(Precursor to study described in Appendix B.7.) One-year study, April, September, and December 1971-1972.

B.6.4. Sampling Methods

Water was sampled at Kenwood Beach, the plant site, and Cove Point. Aliquots were taken for measurements of primary productivity, phytoplankton, pigments, and photosynthetic rate. Hydrographic data were also taken. Phytoplankton samples were incubated on deck and *in situ*.

B.6.5. Analysis

- Individual phytosynthetic rates measured at different depths were graphed; the area under the curve represented integral phytosynthesis (mg of $O_2/m^3/hr$).
- Spatial variation in phytosynthetic rate was estimated by grid sampling.
- Station by depth matrices were constructed for vertical profiles of temperature, salinity, light penetration, and chlorophyll concentration.
- Analyses of variance were used to compare surface and bottom samples.

B.6.6. Results

- Monthly phytoplankton cell counts from surface and bottom sampling are graphed in Fig. B.6-1.
- Monthly chlorophyll *a* concentrations are shown in Fig. B.6-2.
- Monthly deck-tank gross photosynthesis rates are graphed in Fig. B.6-3.
- Table B.6-1 presents analyses of variance of differences between surface and bottom values of gross photosynthesis, chlorophyll *a*, and total phytoplankton counts; both factors (i.e., depth and time) were shown to be significant.

B.6.7. Significance and Critique of Findings

Findings must be evaluated relative to those of Appendix B.7.

Table B.6-1. Analyses of variance on time-series data for gross photosynthesis, chlorophyll a, and total phytoplankton counts (from Ref. 30).

GROSS PHOTOSYNTHESIS - 12 months (Missing Replicates)

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Statistic
Depth: Surface and Bottom	220,819.6	1	220,819.6	58.90*
Time: Month intervals	2,054,086.6	11	186,735.2	49.82*
Depth by time interaction	1,545,770.9	11	140,524.6	37.49*
Error	59,974.0	16	3,748.4	--
Totals	3,880,651.1	39		

CHLOROPHYLL a - 13 months data

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Statistic
Depth: Surface and Bottom	4,388.4	1	4,388.4	162.0*
Time: Month intervals	30,439.0	12	2,536.6	93.6*
Depth by time interaction	23,959.2	12	1,996.6	73.7*
Error	704.5	26	27.1	--
Totals	59,491.1	51		

TOTAL PHYTOPLANKTON - 13 months data

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Statistic
Depth: Surface and Bottom	448,446.9	1	448,446.9	447.5*
Time: Month intervals	2,828,425.3	12	235,702.1	235.2*
Depth by time interaction	2,794,360.8	12	232,863.4	232.4*
Error	26,055.5	26	1,002.1	--
Totals		51		

* Minimal Significance Level at 5 %

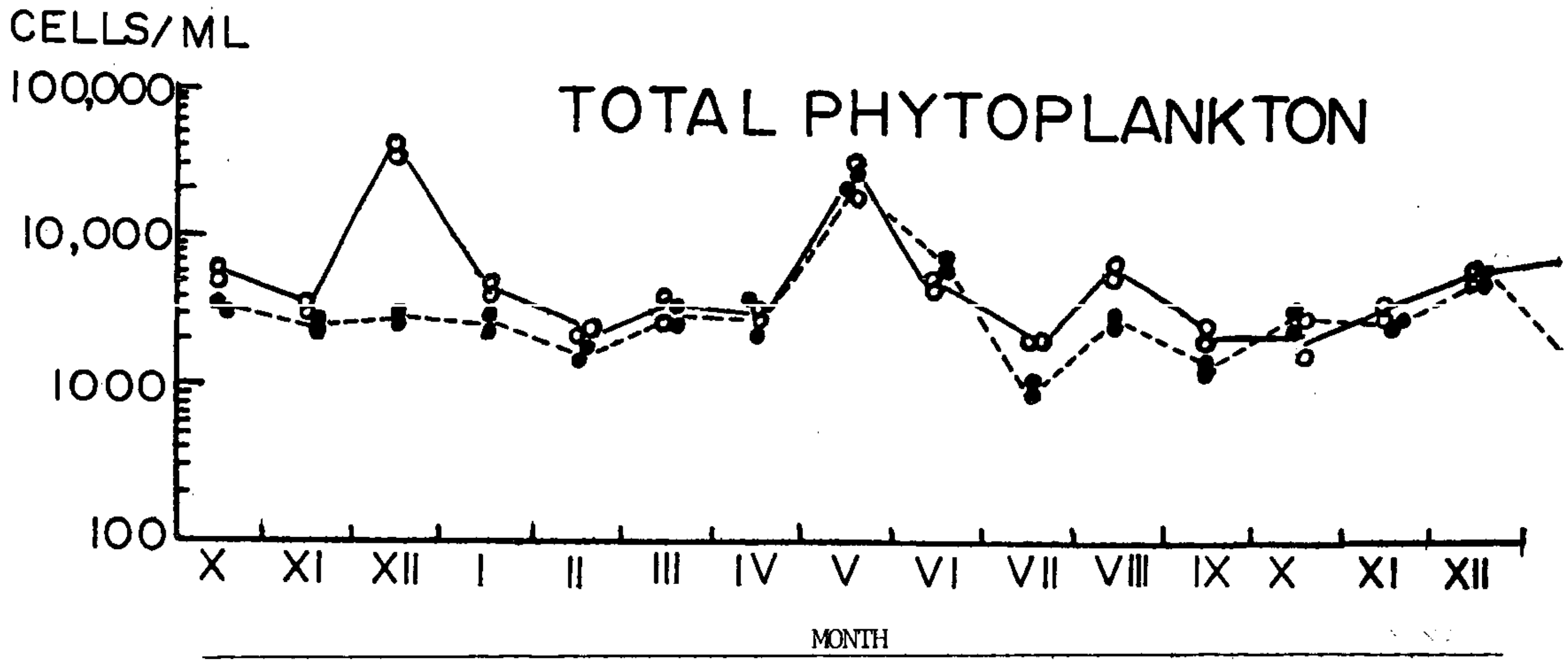

Figure B.6-1. Monthly phytoplankton cell counts from October 1971 - December 1972 (from Ref. 30). Surface (-o-) and Bottom (--•--).

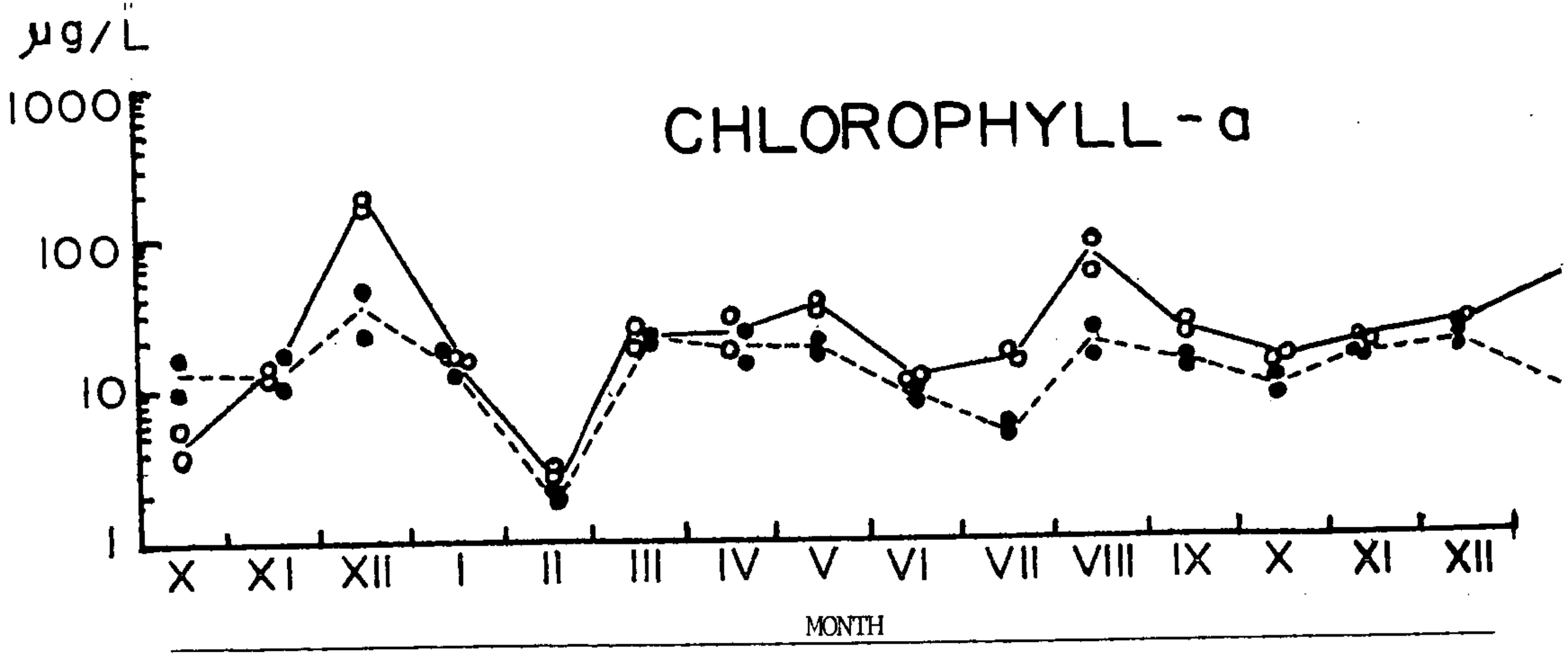

Figure B.6-2. Monthly phytoplankton chlorophyll a from October 1971 to December 1972 (from Ref. 30). Surface (-o-) and Bottom (--•--).

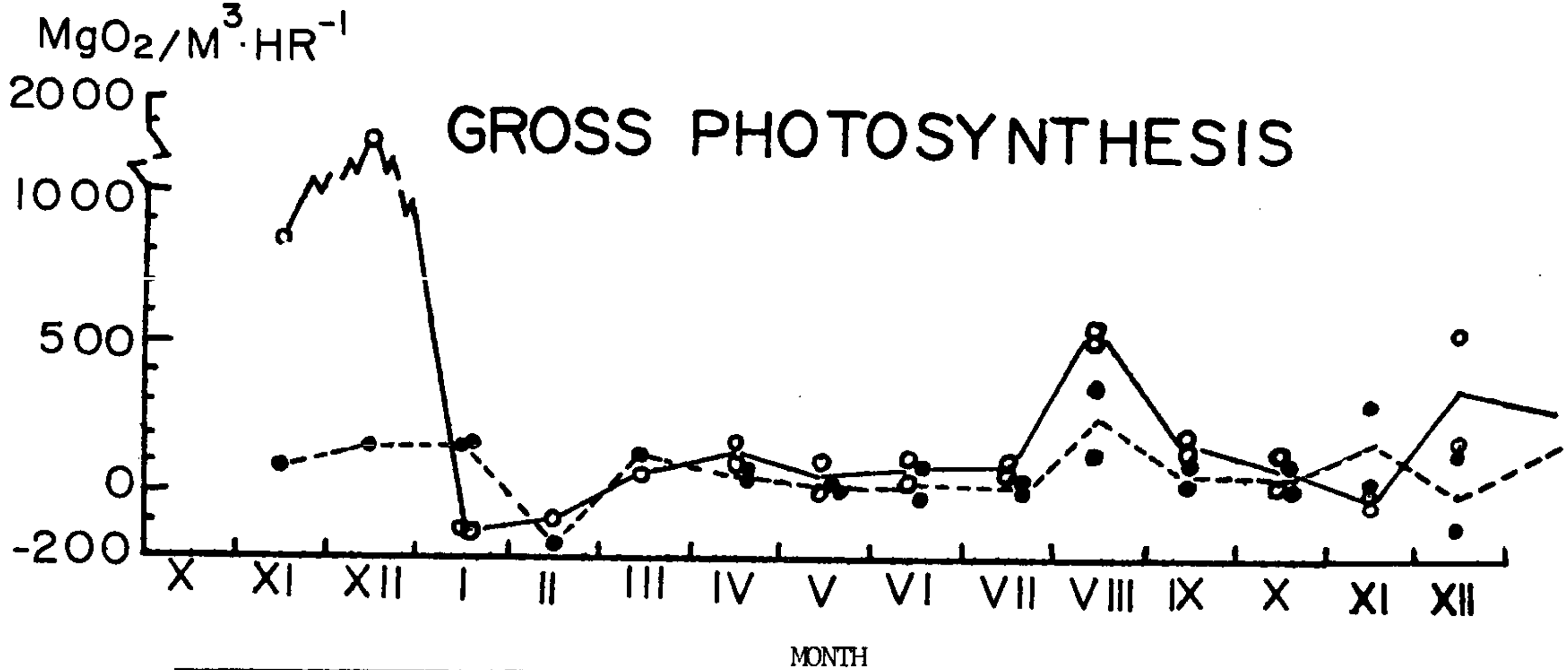

Figure B.6-3. Monthly deck-tank gross photosynthesis from October 1971 to December 1972 (from Ref. 30). Surface (-o-) and Bottom (--•--).

APPENDIX B.7. - PHYTOPLANKTON: PRODUCTIVITY AND BIOMASS

(ANSP)

B.7.1. Objective

To determine the effect of plant operations on the phytoplankton population of Chesapeake Bay.

B.7.2. Data Sources

Sections 6 in Refs. 1, 2; Section 5 in Ref. 164; and Refs. 38-42.

B.7.3. Study History

From 1975 to present. Duplicate surface samples collected through 1975. Triplicate surface samples collected 1976-1979. Duplicate bottom samples collected since 1975.

B.7.4. Sampling Methods

Whole-water samples were collected monthly for the entire study at Kenwood Beach, Long Beach, the plant site, Rocky Point, Cove Point, Flag Pond, Camp Conoy, and the plant site intake. Samples were incubated on-deck at surface-light intensities. Gross photosynthesis, net photosynthesis, respiration, and active chlorophyll a were measured throughout the entire study. Nonmetallic sampling devices were used: PVC Kemmerers, hand pumps, and Van Dorn bottles.

B.7.5. Analysis

- Harmonic regression methods were used to remove the systematic cyclic trends that occurred annually from 1975 to 1979.
- Using residuals obtained by detrending, 95% confidence intervals were obtained for gross and net photosynthesis; other data sets (e.g., chlorophyll) were not amenable to testing because of trends in residuals.
- In 1977, Friedman Rank Sums Analyses were used to test similarity between depths and stations.
- The 1979 data were plotted and some box and whisker plots were prepared.

B.7.6. Results

- Gross photosynthesis

  -- The yearly maximum was reached in July 1977, August 1975, 1976, 1978, and September 1979.

  -- No apparent up-bay or down-bay trends were apparent during 1976 through 1979.

  -- On 11 of 16 occasions during June, July, August, and September of 1976 and 1977, plume station gross photosynthesis values were substantially lower than the nearfield mean (Table B.7-1); a similar pattern occurred in 1979.

  -- Higher gross photosynthesis values were observed at the plume station in the winters from 1975 to 1978, but not in 1979.

  -- Despite the consistency of differences observed, values at the plume station were not statistically different from the nearfield mean; thus, the depression and stimulation were small in magnitude.

- Net photosynthesis

  -- The yearly maximum value occurred in August in the years 1975 to 1978 and in September in 1979.

  -- No apparent up-bay or down-bay patterns existed during the 5 years.

  -- Depressed values at the plume station existed in 38 of 57 months, e.g., Table B.7-2, with most occurring in summer.

  -- Some enhancement occurs at the plume station in winter in the years 1975 through 1978.

  -- Plume values and nearfield means were not significantly different from each other, despite the consistency of stimulation and inhibition.

- Respiration

  -- Maximum rates occurred in the warm summer months from 1975 to 1979.

  -- No apparent up-bay or down-bay pattern was observed during the 5-year period.

  -- Plume respiration rates were greater than the nearfield mean in 33 of 57 months, e.g., Table B.7-3; however, this influence was shown year-round.

-- During 1978, the respiration value at the discharge was higher than the nearfield mean in every month, a phenomenon not observed in the years 1975 through 1977, or in 1979.

-- Because of trends in the data, station differences could not be contrasted statistically.

- Other Factors

  -- No significant difference between plume and nearfield mean values were found for assimilation ratios, percent phaeopigment, or active chlorophyll a.

  -- There was no apparent up-bay or down-bay trend for assimilation ratios, percent phaeopigment, active chlorophyll a (except in 1975), temperature, or dissolved oxygen values.

  -- Strong seasonal variation occurred in the gross and net assimilation ratio data.

  -- Temperatures were consistently higher (2-3°C) in the plume station than they were in the nearfield.

  -- Maximum salinities usually occurred during the summers; a slight trend of lower up-bay salinities was recorded.

  -- The plume station consistently showed lower dissolved oxygen values than the nearfield mean, resulting from lower D.O. concentrations in the deeper waters withdrawn for cooling.

B.7.7. Significance and Critique of Findings

Plant operations appear to cause winter stimulation and summer depression of productivity in the plume area; however, the magnitude of the effect is small and data variability is large, so the effects are not statistically significant. Also, the effects appear to be localized, since nearfield station analyses (not presented here) show no patterns of effect.

Table B.7-1. Comparison of nearfield mean ($\bar{X}$) and plume A (PLA) gross photosynthesis values in mg O_2/m^3/hr, CCNPP, Chesapeake Bay, between 1975 and 1978 (from Ref. 1).

	MONTH											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975 $\bar{X}$	*	34.1	41.4	25.9	53.2	145.7	230.0	749.3	554.2	198.2	227.5	125.7
PLA			233.4	6.4	70.1	142.3	303.2	885.3	364.4	247.4	205.5	86.8
1976 $\bar{X}$	48.7	14.6	30.0	59.8	76.7	208.4	485.3	491.1	360.0	147.6	55.8	47.3
PLA	72.5	34.3	64.0	120.9	317.9	83.3	202.5	511.1	22.7	71.2	206.6	68.3
1977 $\bar{X}$	*	39.5	22.6	26.5	139.4	186.7	388.7	345.3	195.0	301.7	115.7	-148.1
PLA		57.2	21.6	57.7	127.7	150.2	142.8	167.8	141.2	405.0	88.3	- 49.8
1978 $\bar{X}$	- 6.4	50.8	62.6	91.0	56.2	273.9	414.7	584.8	282.4	301.2	82.4	186.4
PLA	60.7	67.2	59.7	96.7	112.9	220.8	361.5	581.9	189.7	348.9	32.4	136.0

* no data due to ice cover on bay

Table B.7-2. Comparison of nearfield mean ($\bar{X}$) and plume A (PLA) net photosynthesis values in mg $O_2/m^3/hr$, CCNPP, Chesapeake Bay, between 1975 and 1978 (from Ref. 1).

	MONTH											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975 $\bar{X}$	*	19.7	46.2	-12.7	10.8	106.4	144.6	568.4	480.3	169.7	157.5	-25.2
PLA			58.3	-4.3	32.7	85.4	190.0	708.6	286.3	229.2	117.0	18.6
1976 $\bar{X}$	-2.2	32.9	-6.4	-14.6	-5.4	134.9	377.4	471.4	221.5	112.5	58.9	47.8
PLA	78.8	45.0	27.3	129.6	244.4	12.6	117.5	424.8	-28.2	29.5	171.4	33.4
1977 $\bar{X}$	*	10.5	-11.4	45.7	89.6	133.6	307.5	323.6	175.9	230.3	102.9	-225.7
PLA		60.3	-11.9	31.7	56.7	91.7	67.1	63.1	119.4	468.7	63.2	-225.7
1978 $\bar{X}$	55.7	48.3	36.2	36.1	35.6	192.0	331.5	460.3	252.2	265.4	82.3	173.9
PLA	54.3	53.6	27.2	18.2	13.4	136.3	239.4	438.4	152.8	281.2	-2.6	106.8

* no data due to ice cover on Bay.

Table B.7-3. Comparison of nearfield mean ($\overline{X}$) and plume A (PLA) respiration values in mg $O_2/m^3/hr$, CCNPP, Chesapeake Bay, between 1975 and 1978 (from Ref. 1).

	MONTH											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975 $\overline{X}$	*	14.3	16.8	48.6	42.4	39.3	85.4	184.0	73.9	28.5	70.0	95.0
PLA			175.0	10.6	37.4	56.9	113.2	176.6	78.1	18.2	88.4	68.2
1976 $\overline{X}$	50.9	-18.3	36.4	74.3	82.1	73.5	107.8	30.4	138.5	35.1	-3.1	-.46
PLA	-6.3	-10.7	36.7	-8.7	73.4	70.7	85.0	86.3	50.9	41.7	35.2	34.9
1977 $\overline{X}$	*	29.1	33.9	-19.2	49.9	53.1	81.1	21.8	17.9	71.6	12.9	138.5
PLA		-3.2	33.5	35.9	71.0	40.1	75.7	104.7	21.8	3.1	25.1	175.9
1978 $\overline{X}$	-62.2	2.5	26.7	55.4	20.6	81.3	83.2	124.5	27.9	35.7	-30.5	12.5
PLA	6.4	15.6	32.5	78.5	99.5	84.5	122.1	143.5	31.2	67.7	35.1	17.9

* no data due to ice cover on Bay.

APPENDIX B.8. - AN ANNUAL PLANKTON CYCLE IN THE CHESAPEAKE BAY IN THE VICINITY OF CALVERT CLIFFS

(R.A. Mulford, ANSP)

B.8.1. Objective

To determine the seasonal variations in basic types and quantities of phytoplanktonic microorganisms in the vicinity of the plant.

B.8.2. Data Source

Ref. 26.

B.8.3. Study History

One-year study, from June 1969 to May 1970.

B.8.4. Sampling Methods

Samples collected monthly using a submersible pump from surface and bottom at Kenwood Beach (KB), the plant site (PS), Rocky Point (RP), and Cove Point (CP). Samples were collected by pumping for five minutes into a 10-μm nannoplankton net. In the laboratory, all species were identified and counted. Temperature, salinity, and D.O. data were collected at each sample depth.

B.8.5. Analysis

Phytoplankton diversity was measured with the Shannon formula:

$$H = \sum_{i=1}^{S} \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

where

H = community diversity
N = total number of individuals per liter
S = number of species
n_i = number of individuals of species i.

B.8.6. Results

- Total phytoplankton cell densities per month at KB, PS, and RP are shown in Fig. B.8-1.

- The phytoplankton population during the winter was dominated by diatoms.
- Throughout the study the population was dominated by relatively few species, including: *Skeletonema costatum*, *Cerataulina bergonii*, *Rhizosolenia calcar avis*, *Asterionella japonica*, *Rhizosolenia fragilissima*, *Coscinosira polychorda*, and tintinnids.
- An out-of-phase February pulse may have been related to a much lower than usual April-May bloom in 1970 (Fig. B.8-1).
- Species diversity in surface samples was slightly lower up-bay (Kenwood Beach station) (Fig. B.8-2).
- Bottom species diversity is shown in Fig. B.8-3.
- Largest numbers of species (Figs. B.8-4 and B.8-5) occurred in the fall period, and more species generally were observed in the bottom samples.
- The Cove Point station data were not plotted, but diversity and species numbers were similar to those for the other stations.

B.8.7. Significance and Critique of Findings

The data are useful to characterize seasonal phytoplankton cycles. Findings must be evaluated relative to those of Appendix B.9.

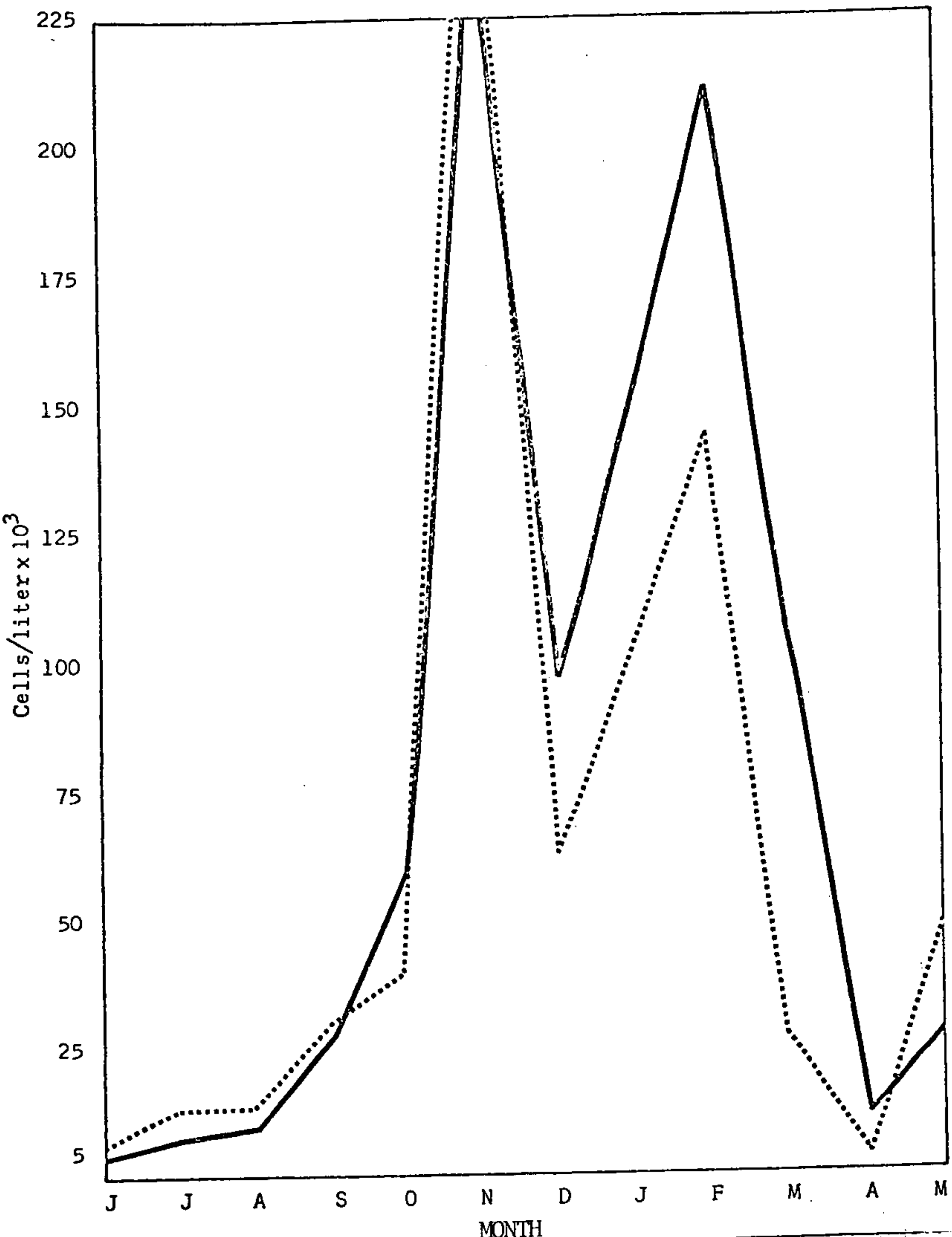

Figure B.8-1. Total plankton population/month (1969-1970) for three Chesapeake Bay stations: Kenwood Beach, Plant Site, and Rocky Point (from Ref. 26).

Surface...... Bottom——

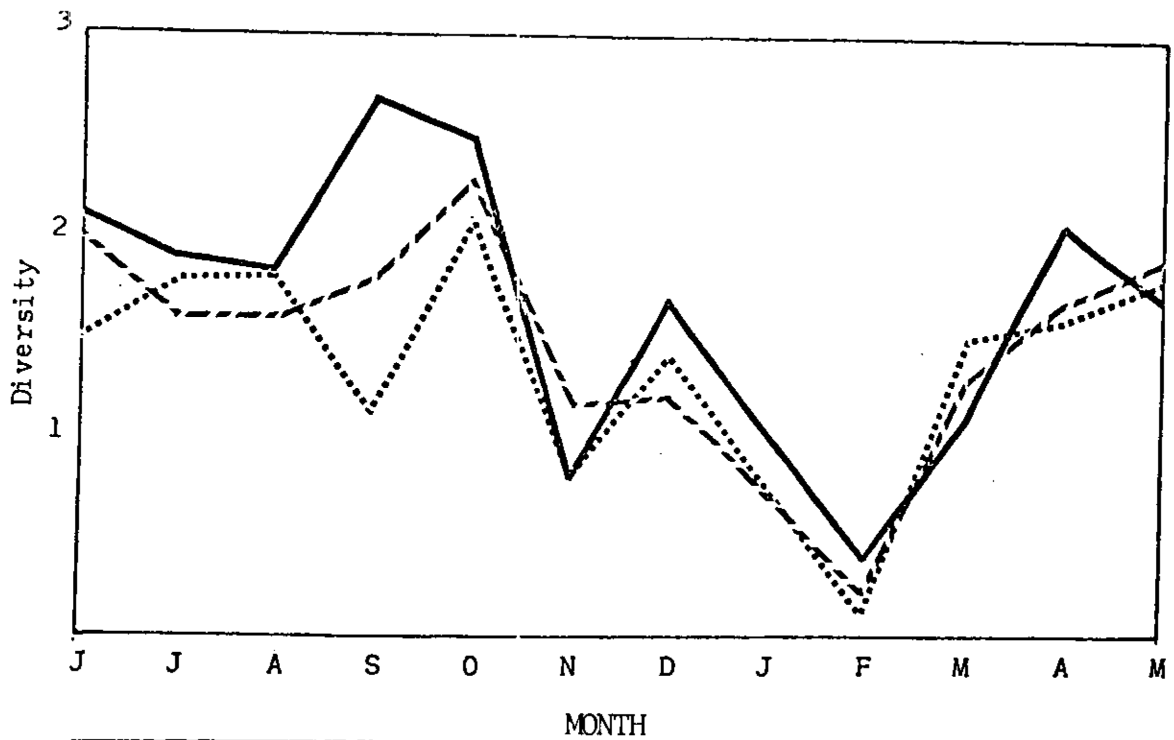

Figure B.8-2. Surface species diversity/month (1969-1970) for three Chesapeake Bay stations (from Ref. 26).

..... Kenwood Beach
----- Plant Site
——— Rocky Point

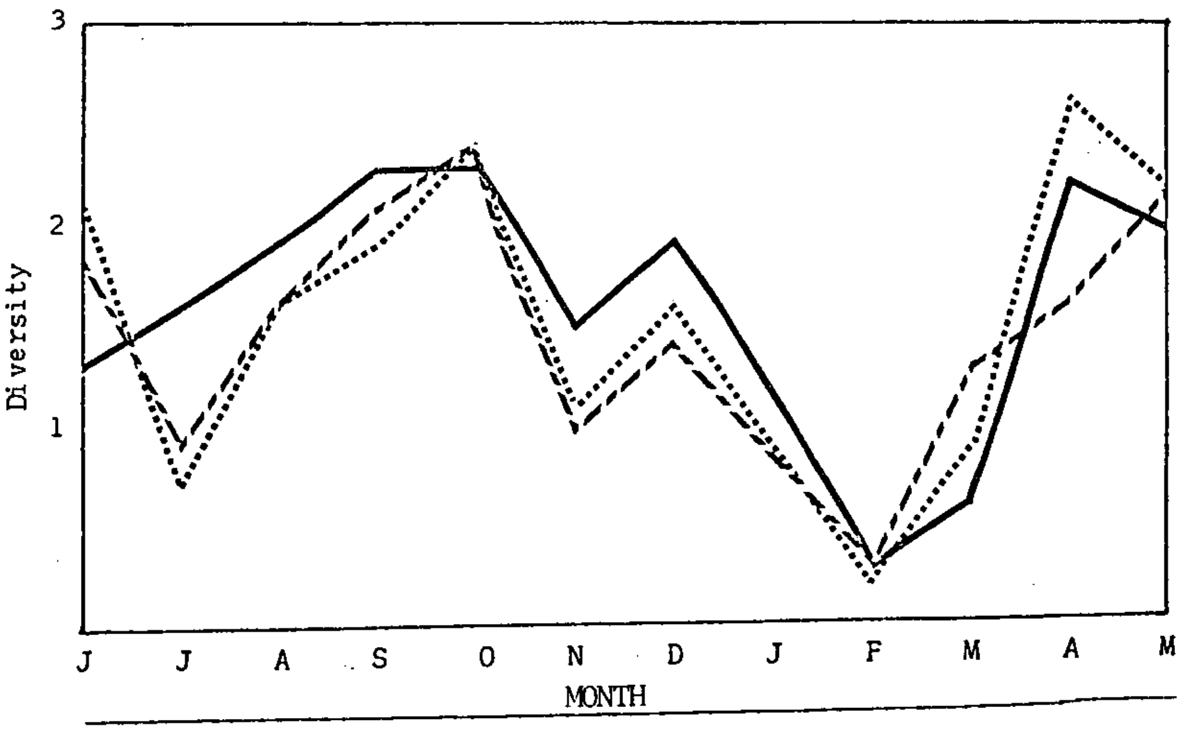

Figure B.8-3. Bottom species diversity/month (1969-1970) for three Chesapeake Bay stations: Kenwood Beach, Plant Site, Rocky Point (from Ref. 26).

.... Kenwood Beach
------- Plant Site
——— Rocky Point

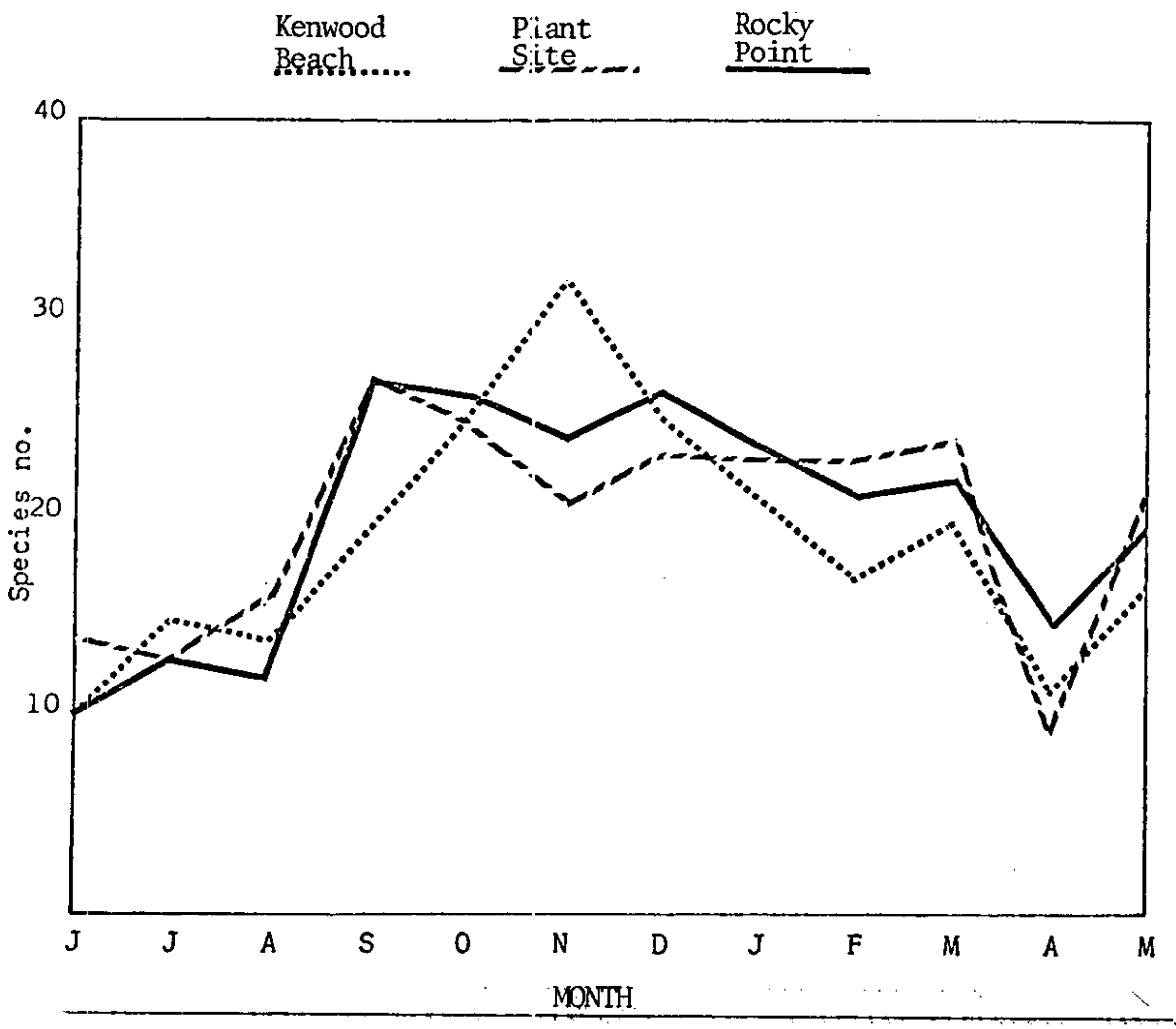

Figure B.8-4. Surface species number/month (1969-1970) for three Chesapeake Bay stations: Kenwood Beach, Plant Site, Rocky Point (from Ref. 26).

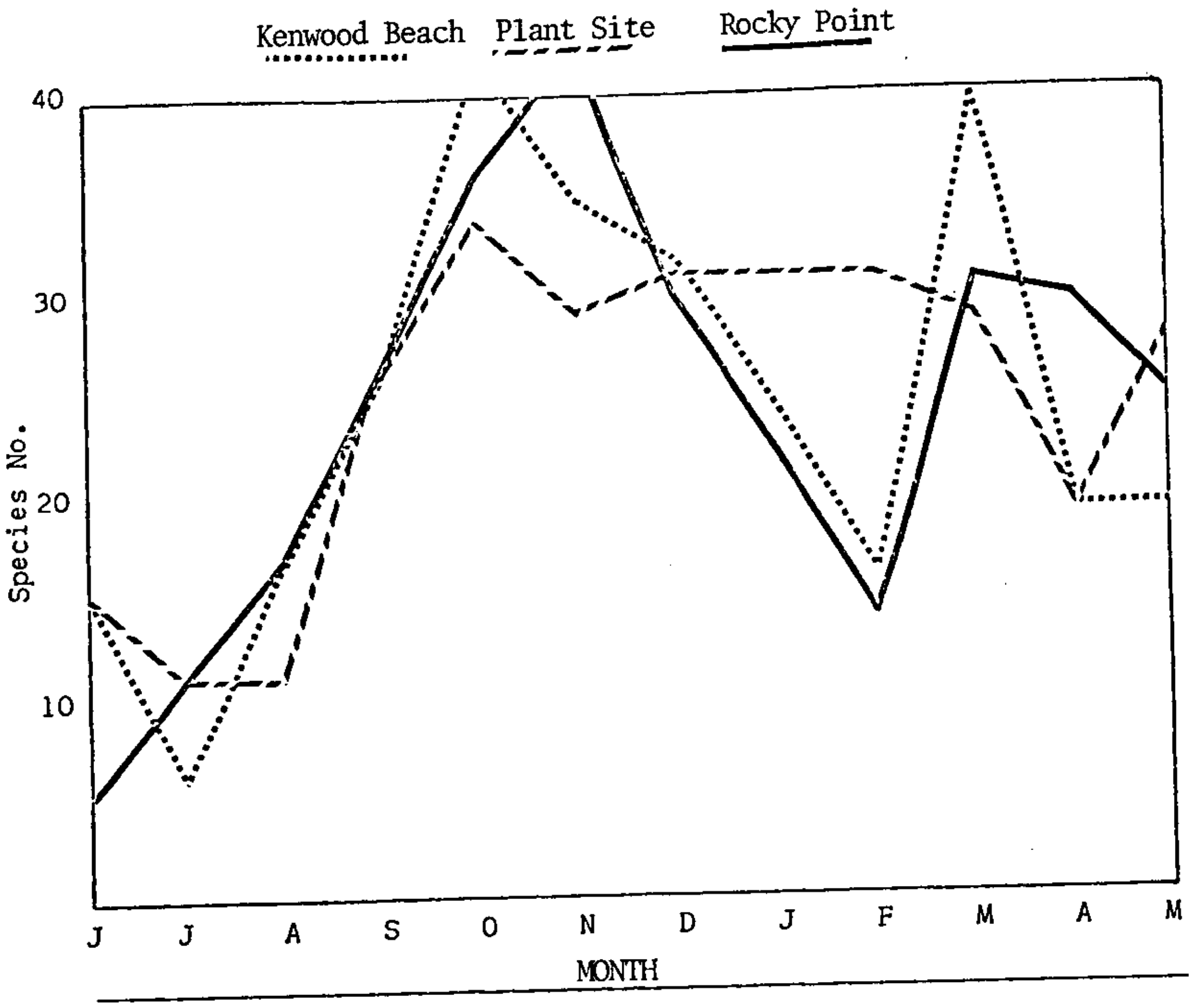

Figure B.8-5. Bottom species number/month (1969-1970) for three Chesapeake Bay stations (from Ref. 26).

APPENDIX B.9. - PHYTOPLANKTON: TAXONOMY

(ANSP)

B.9.1. Objective

To describe the seasonal changes in the nearfield phytoplankton communities in the vicinity of the plant, and to analyze patterns in the abundance, diversity, and species composition of these communities to determine possible plant operation effects.

B.9.2. Data Sources

Sections 7 in Refs. 1, 2; Section 5 in Ref. 164; and Refs. 38-42.

B.9.3. Study History

Six-year study, from 1974-1979.

B.9.4. Sampling Methods

Intake, discharge, and control stations (up-bay and down-bay of the plant) were sampled with a Kemmerer bottle. Duplicate whole-water phytoplankton samples were taken monthly. Samples were fixed and transferred to the laboratory where species composition and abundance were determined.

B.9.5. Analysis

- "Box and whisker" plots were made for station values of cell densities to determine consistent patterns over months that delineated station differences.
- Plots were made of the 2-year average of 1976-1977 monthly cell densities at intake and discharge stations.
- Species diversity was measured using the Shannon-Wiener Diversity Index.
- Similarity of taxonomic composition was determined using the C-lambda and the Jaccard coefficients.
- Spearman rank correlation coefficients were calculated where linear relationships between variables were suspected.
- The 4-year monthly means of 1975-1978 values of nutrient variables, temperature, and solar radiation vs cell counts were plotted.

- Plots of the 4-year monthly means for net photosynthesis and active chlorophyll were also made.
- Monthly values of all variables for 1979 were tabulated and graphed.

B.9.6. Results

- Cell densities of all phytoplankton groups showed surface-bottom differences at all stations, indicating vertical stratification.
- Monthly average total cell densities and cell densities by group for all stations, 1975-1978, are shown in Fig. B.9-1.
- No significant differences in abundance, diversity, and taxonomic composition were identifiable among stations.
- No consistent statistical differences between stations were found in total phytoplankton cell densities or cell densities by taxonomic division.
- Species diversities among stations by month were similar, and no consistent patterns were found, although some seasonal trends were demonstrated.
- There was weak evidence of a gradient of decreasing total cell densities from up-bay to down-bay nearfield stations in 1975 and 1976.

B.9.7. Significance and Critique of Findings

- It appears that station differences reflect a natural gradient in phytoplankton density along the Bay axis.
- None of the measured variables suggest the existence of a plant effect.

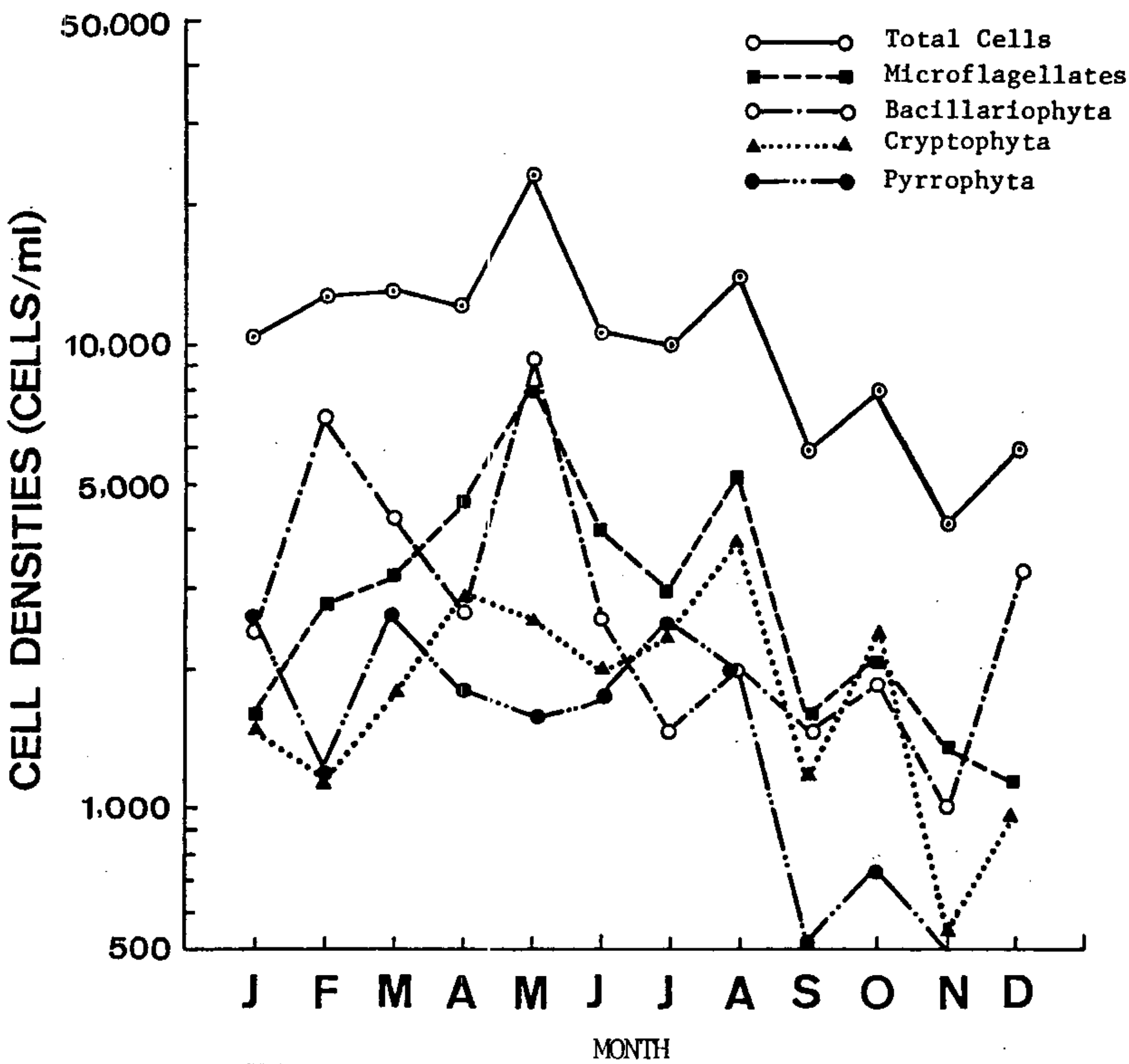

Figure B.9-1. Cell densities. Monthly average total phytoplankton cell densities and cell densities by taxonomic division for stations in the vicinity of Calvert Cliffs Nuclear Power Plant, 1975-1978 (from Ref. 1).

APPENDIX B.10. - CATHERWOOD DIATOMETER READINGS

(ANSP)

B.10.1. Objective

To monitor water quality at the plant site as reflected by diatom community structure.

B.10.2. Data Sources

Refs. 22, 23.

B.10.3. Study History

Study done from May 1971 through April 1973; no operational data collected.

B.10.4. Sampling Methods

Four stations, located near Governor Run, Long Beach, Camp Conoy, and Rocky Point, were sampled biweekly. Catherwood diatometers anchored in floating position at each station were used to collect diatoms. In the laboratory, slides containing dried diatoms were scraped for observation and tabulation of abundances and types of diatoms.

B.10.5. Analysis

The data were plotted as truncated normal curves. The ordinate, which is an arithmetic scale, represents the number of species; the abscissa, which is a logarithmic scale, represents the number of individuals per species.

B.10.6. Results

- During the spring and winter months, growth was very low at all stations.
- During July and August 1972, seasonally high water temperatures intensified the effects of mineralized organic loading, resulting in very high growth at Governor Run.
- Influences of toxic loading were generally minor as shown by species diversity readings.

- During July and August 1971 at Camp Conoy and Rocky Point, respectively, heavy mineralized organic enrichment was evidenced by very high diatom growth.

B.10.7. Significance and Critique of Findings

Since the study was not continued after plant operations began, findings have little direct relevance to plant effects.

APPENDIX B.11. - PHYTOPLANKTON ENTRAINMENT

(ANSP)

B.11.1. Objective

To assess entrainment effects on phytoplankton.

B.11.2. Data Source

Ref. 168.

B.11.3. Study History

Work was conducted in 1978 and 1979.

B.11.4. Sampling Methods

Pumped samples were taken from the intake, the discharge conduit, and the plume over one 24-hour period each month from June through September in 1978 and 1979. Samples at the intake were taken from depths of 1, 3, and 5 meters simultaneously. Samples were taken hourly for determination of species composition and chlorophyll _a_ concentration. The ^{14}C productivity was measured every half hour during daytime and O_2 production every hour during daytime.

B.11.5. Analysis

- Ratios of cell densities (smoothed over the 24-hour series) between intake and discharge conduit and intake and plume were calculated; median ratios and their confidence limits were calculated for each 24-hour period; box and whisker plots were made.
- The ^{14}C productivity and chlorophyll _a_ data were treated in the same manner.

B.11.6. Results

- Reductions in flagellated cells between intake and discharge were frequently observed, but increases also were seen; inconsistent results were attributed to sampling problems.
- In 1978, productivity was depressed as a consequence of entrainment, while in 1979 it was apparently enhanced (Table B.11-1); results from oxygen studies were variable.

- Results were considered too variable to permit a true assessment of entrainment effects.

B.11.7. Significance and Critique of Findings

There were many sampling problems encountered in this study, so the results are inconsistent. No conclusion can be drawn about the magnitude or nature of entrainment effects.

Table B.11-1. Monthly medians of ^{14}C half-hourly discharge-to-intake ratios with 95% confidence intervals* for the true medians (from Ref. 168).

	Median	95% Confidence Interval**
1978		
June	0.76	0.66 - 1.06
July	0.74	0.63 - 0.78
August	0.78	0.69 - 0.87
September	0.25	0.15 - 0.28
1979		
June	3.58	1.55 - 5.56
July	0.91	0.79 - 1.07
August	1.02	0.78 - 1.42
September	1.57	1.08 - 1.73

* Distribution-free confidence intervals based on the Sign Test.

** The confidence levels actually vary from 94% to 98% because they are based on discrete distributions with parameters depending on sample size.

C APPENDICES

ZOOPLANKTON STUDIES

APPENDIX C.1. - ZOOPLANKTON ENTRAINMENT STUDY

(L.E. Sage and M. Olson, ANSP)

C.1.1. Objective

To assess the effect of entrainment on zooplankton abundance and mortality.

C.1.2. Data Sources

Refs. 40-42.

C.1.3. Study History

Entrainment studies using the sampling design discussed here were carried out in 1975 and 1976; further entrainment studies used a modified sampling design (see Appendix C.2).

C.1.4. Sampling Methods

- Nineteen 1-liter samples were taken with a diaphragm pump at intake, tunnel-access, and discharge locations. Until August 1975, intake samples were taken at three depths in front of the plant's intake screens. After this date, the intake station was moved to a location behind the screens, where samples were taken from a single depth.
- Monthly 24-hour zooplankton collections, consisting of six sampling periods spaced at 4-hour intervals, were taken. Seven replicate samples were taken for each station, depth, and time combination.
- All samples were vitally stained using neutral red dye (see Ref. 40 for details of staining procedure).

C.1.5. Analysis

Density estimates of total zooplankton and individual species and life stages were determined and compared among intake, tunnel-access, and discharge locations. Differential survival (expressed as percent alive) was tabulated at intake, tunnel-access, and discharge locations. Confidence limits were established, and data were tested for differences by ANOVA methods (Ref. 40, pp. 13.2-7; Ref. 41, pp. 13.2-12). Alternate methods for calculating confidence limits for 1976 data are presented in Ref. 42, pp. 13.2-3.

C.1.6. Results

- Results from 1975 indicated that on an average throughout the year, total zooplankton numbers were reduced by 30% upon passage through the plant (Fig. C.1-1). Results from 1976 generally indicated a reduction in numbers of organisms from intake to discharge (Fig. C.1-2). As in 1975, the greatest reduction in 1976 occurred in August and September.

- Analysis of the reduction in density by species and age class indicated that primary losses in density occurred for copepod nauplii. A similar trend, though not as pronounced, was also observed for *Acartia tonsa* copepodids and, to a lesser extent, for *A. tonsa* adults.

- The total number of zooplankters (all species) collected at the intake in May and June 1976 was less than numbers taken at the other locations. In these months, barnacle larvae were abundant and often dominated the samples.

- An estimated 95% of zooplankters collected during the first part of 1975 were alive, and there was little difference between percentages alive at the intake and discharge locations (Fig. C.1-3). Survival data collected for the second half of 1975 were not considered accurate due to problems with the staining procedure. Throughout most of 1976, more than 89% of organisms at all locations were alive (Fig. C.1-4), and percentages were not significantly different at intake, tunnel-access, and discharge sites.

C.1.7. Significance and Critique of Findings

- The overall reduction in density between intake and discharge locations could be indicative of plant-induced mortality. However, observed high numbers of living organisms at all locations, coupled with a lack of difference in the survival rate between sampling locations, suggest the possibility either of organisms receiving extreme mechanical damage during plant passage, of unrepresentative zooplankton sampling resulting in underestimates at discharge stations, or predation on entrained organisms by barnacles lining the cooling system (see Appendix C.3).

- Greater numbers of total zooplankton were observed at the discharge location than at the intake location in May and June 1976. The increase may be the result of barnacle nauplii being produced in the discharge conduits (see Appendix C.3).

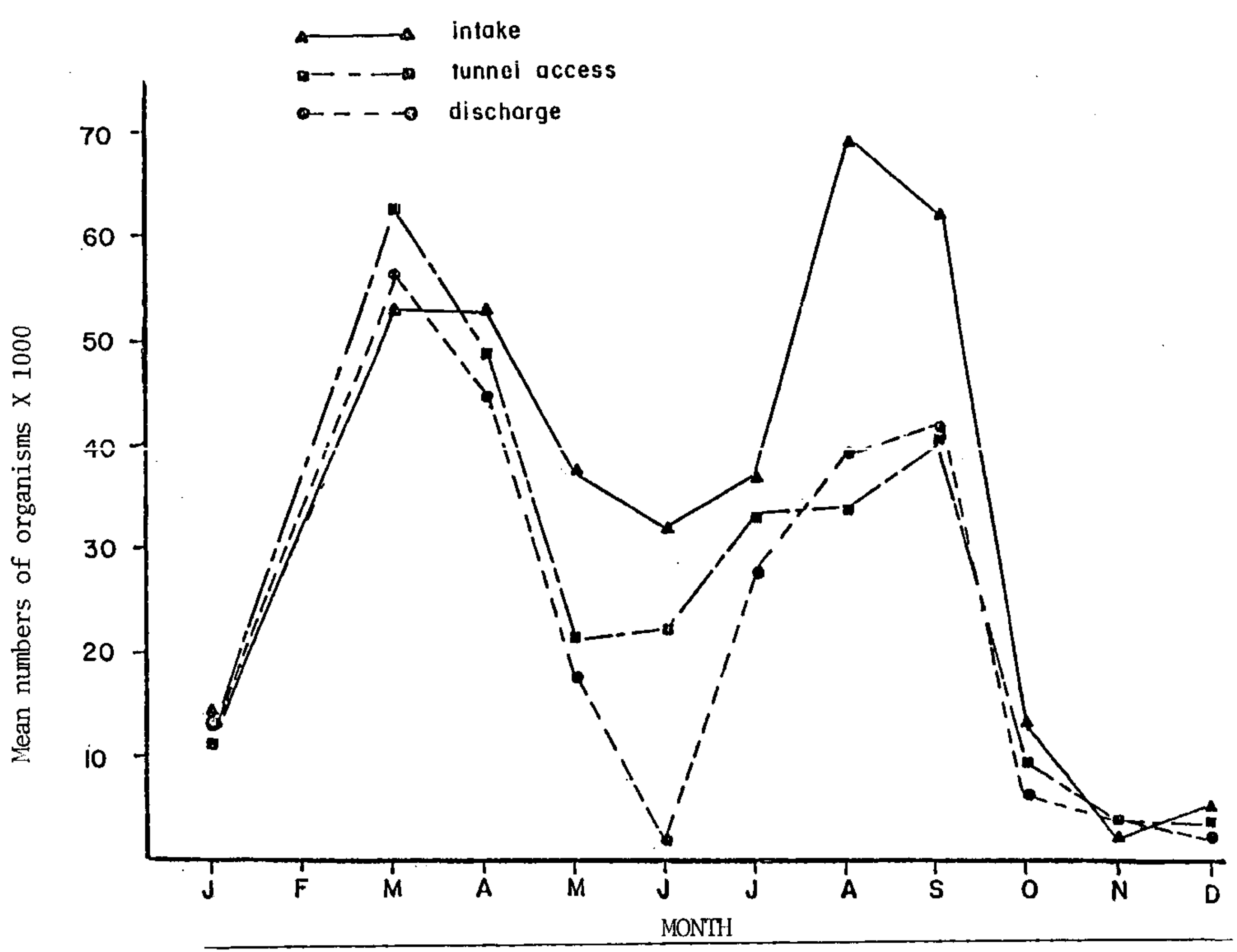

Figure C.1-1. Mean numbers of entrained zooplankton $\times 10^3$ at all stations, Calvert Cliffs Nuclear Power Plant, 1975 (from Ref. 40).

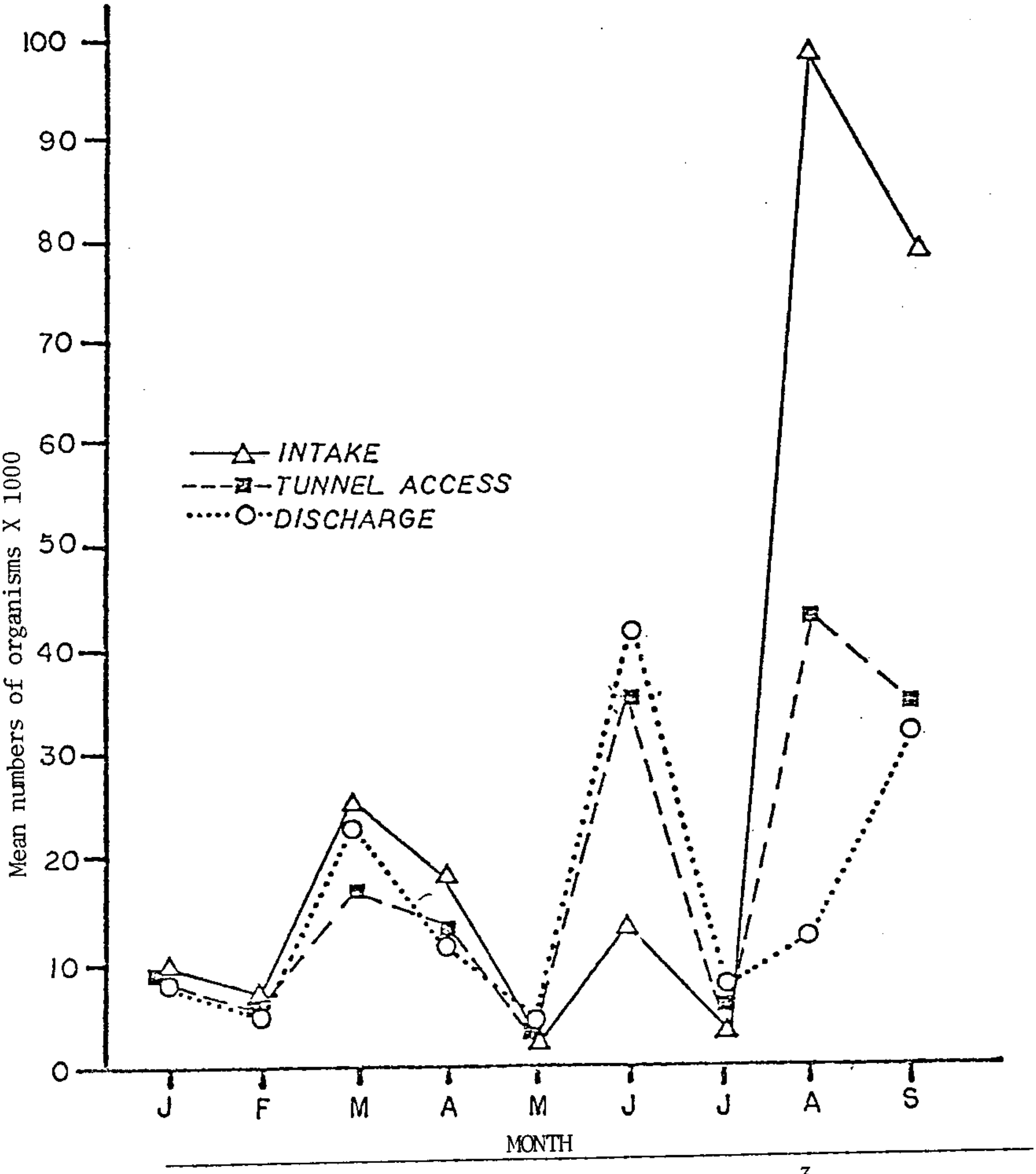

Figure C.1-2. Mean number of entrained zooplankton x 10^3 at all stations, Calvert Cliffs Nuclear Power Plant, for January - September, 1976 (from Ref. 42).

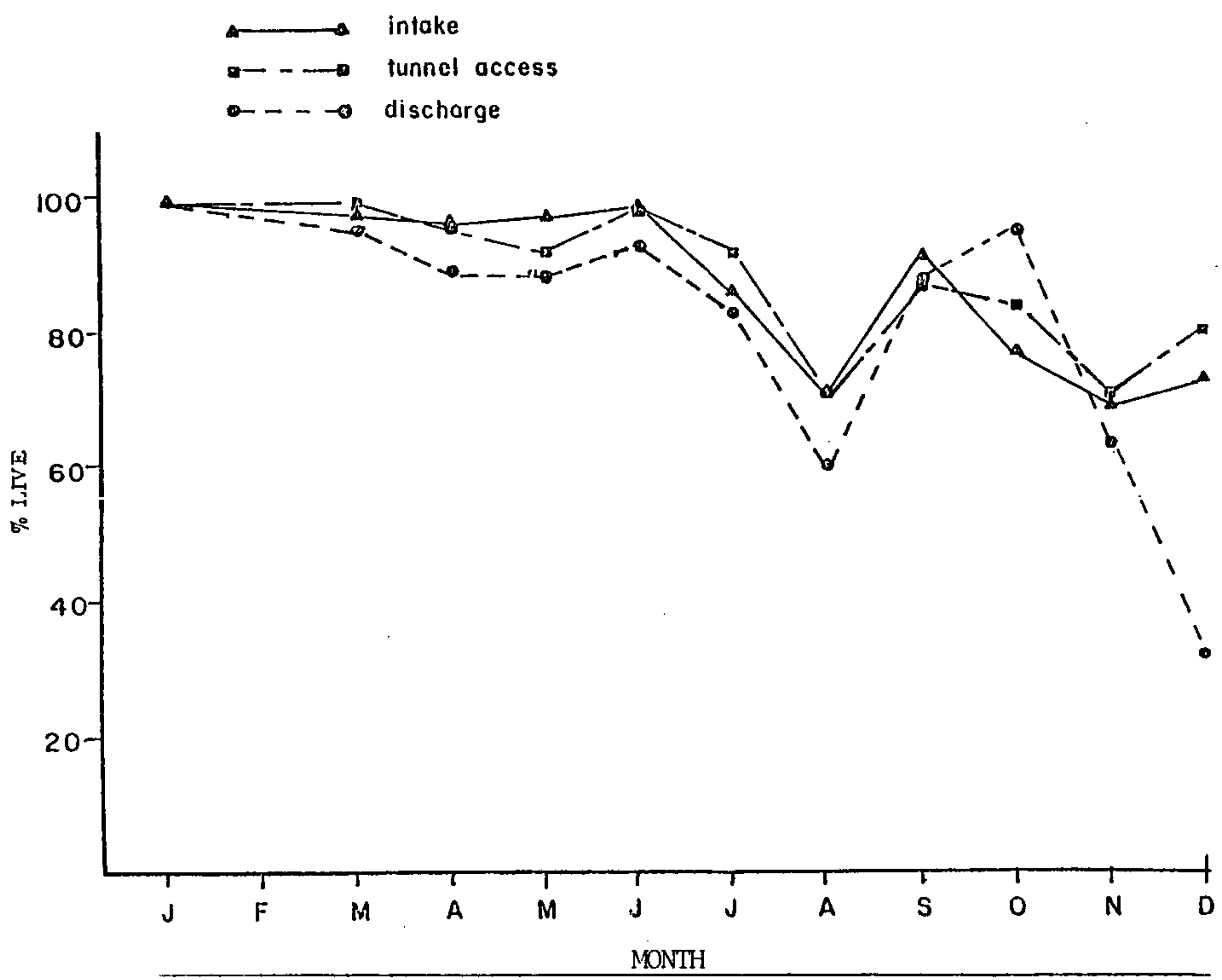

Figure C.1-3. Mean survival rate of zooplankton entrained at Calvert Cliffs Nuclear Power Plant, 1975 (from Ref. 40).

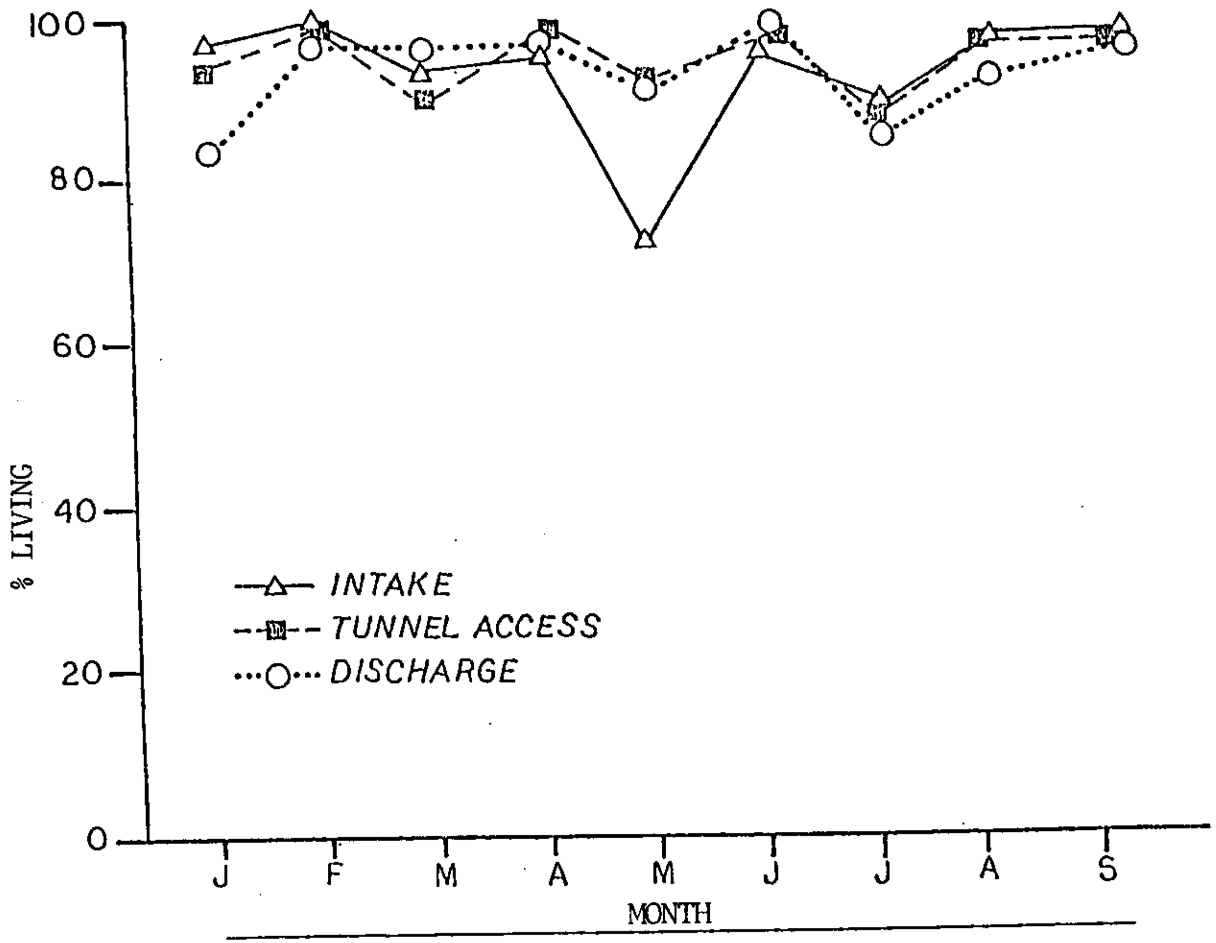

Figure C.1-4. Mean survival rate of zooplankton entrained at Calvert Cliffs Nuclear Power Plant, for January- September, 1976. Data for January - June are included in September 1976 Semi-annual report (from Ref. 42).

APPENDIX C.2. - ZOOPLANKTON ENTRAINMENT STUDY

(ANSP)

C.2.1. Objective

To assess the effect of entrainment on zooplankton mortality and abundance.

C.2.2. Data Sources

Refs. 1, 2, 114, 172.

C.2.3. Study History

Studies conducted during summer months of 1977, 1978, and 1979 as a continuation of the work discussed in Appendix C.1.

C.2.4. Sampling Methods

- In 1977, sampling was conducted twice in June and once each in July, August, and September.
- In 1978 and 1979, sampling was conducted once in June, twice in July, twice in August, and once in September.
- Single 19-liter samples were collected at the plant intake and discharge every 30 minutes throughout a 48-hour period in 1977 and a 24-hour period in 1978 and 1979.
- Samples were obtained with 8-gal/min diaphragm pumps.
- Each intake sample consisted of a composite of water from three depths spaced vertically across the diameter of the circulating-pump, approach conduit. Discharge samples were not composited by depth.
- Samples were vitally stained using neutral red dye (see Ref. 2 for details of staining and counting procedures).

C.2.5. Analysis

Densities of individual species and life stages were compiled. Survival rate was estimated by calculating the ratio of the density of dye-specific (living) zooplankton at the discharge to the corresponding density at the intake. Spectral analysis was applied to square-root-transformed data to obtain statistically valid confidence intervals on the survival rate.

C.2.6. Results

- Certain species or life stages showed reductions in total numbers between intake and discharge locations. In all years, losses were seen primarily in copepod nauplii and *Acartia tonsa* copepodids and, to a lesser extent, in *A. tonsa* adults and polychaete larvae (Tables C.2-1, C.2-2, and C.2-3).

- Results of the spectral analysis of data revealed cyclic density patterns over time for total zooplankton abundances and for abundances of individual species and age classes. The most common cycle periods were 12 and 24 hours.

- Although the fluctuations in zooplankton densities at the discharge paralleled those at the intake, the differential between corresponding intake-discharge samples, a measure of the cropping rate, was not constant over time. In 1977, cropping rate at night was 20 to 80% for *Acartia tonsa*, with copepodids and nauplii showing the greatest effects. During the day, the rate was substantially less (15 to 30%). In 1978, losses increased with increasing overall density for organisms that showed a cropping effect. Results in 1979 were consistent with those of the previous two years; however, densities were generally two to five times greater than those observed during 1977 and 1978.

- Species composition and abundance of zooplankton entrained at Calvert Cliffs generally were similar to that in the nearfield in 1978 (Fig. C.2-1) and 1979 (Fig. C.2-2). Exceptions to this pattern occurred in August and September 1978. The large differences between numbers of *Acartia tonsa* adults entrained and numbers in the nearfield (Fig. C.2-1) observed in August and September 1978 may be explained by the vertical migratory behavior of the organisms.

- Survival statistics (as percent live) in 1978 generally were consistent with results from 1977 (Table C.2-4) and earlier studies. There was a relatively low level of observable mortality. The percentage of dye-specific (live) organisms in 1977 and 1978 samples generally was well over 90%, with little difference evident between intake and discharge locations (Tables C.2-1 and C.2-2).

- In June and July 1978 and on all sampling dates in 1979, barnacle larval densities at the discharge exceeded densities at the intake.

C.2.7. Significance and Critique of Findings

- Results of these studies support results of earlier entrainment studies at Calvert Cliffs. As in previous years, the 1977, 1978, and 1979 data suggest that a loss of organisms occurs between the intake and discharge, while there is no relative increase in the numbers of dead organisms between intake and discharge. This finding suggests that the loss of organisms between intake and discharge might be attributable to either extreme mechanical damage or unrepresentative sampling.

- Because A. tonsa inhabit deeper waters during daylight hours, the probability of entraining them increases during the day (cooling water at Calvert Cliffs is drawn from deeper waters). However, results of other studies (see Appendix C.7) did not indicate a significant plant-related depletion of A. tonsa adults.

- Cropping losses that increase with increasing density over the short term have not been adequately explained and may be due to unrepresentative sampling at the discharge location.

- Increased numbers of barnacle larvae at discharge locations may be due to nauplii being produced in the discharge conduits (see Appendix C.3).

Table C.2-1. Mean densities for the abundant zooplankton species collected at the intake and discharge of the Calvert Cliffs Nuclear Power Plant for each sampling date in 1977 (from Ref. 2).

	INTAKE Mean Total	Mean Alive	% Living	DISCHARGE Mean Total	Mean Alive	% Living
June 7-8						
Polychaete larvae	1291	1280	99	860	858	100
Copepod nauplii	2534	2451	97	1166	1144	98
Cirriped nauplii	854	791	93	1860	1819	98
Acartia copepodites	2249	2217	99	1135	1124	99
Acartia tonsa	174	164	94	165	160	97
Others	2518	2412	-	1946	1879	-
Total (excluding cirriped nauplii)	6248	6112	97	3326	3286	98
Dye specific species	3716	3662	98	2161	2143	99
June 28-29						
Polychaete larvae	677	676	100	585	585	100
Copepod nauplii	10055	9936	99	7153	7089	99
Cirriped nauplii	5485	5370	98	3812	3776	99
Acartia copepodites	2707	2667	98	1821	1801	99
Others	2370	2049	-	2695	2124	-
Total (excluding cirriped nauplii)	13439	13279	97	9559	9475	95
Dye specific species	3534	3484	99	2537	2514	99
July 12-13						
Polychaete larvae	1028	1028	100	967	966	100
Copepod nauplii	8216	7858	96	6542	6117	93
Cirriped nauplii	4107	4009	98	8197	8096	99
Acartia copepodites	13790	13500	98	8781	8646	98
Acartia tonsa	6527	6389	98	5975	5879	98
Others	2249	1844	-	2626	2018	-
Total (excluding cirriped nauplii)	29561	28775	96	22265	21608	95
Dye specific species	21440	21012	98	15729	15491	98
August 9-10						
Polychaete larvae	599	566	94	645	644	100
Copepod nauplii	20456	20153	98	7816	7708	98
Cirriped nauplii	747	709	95	1200	1171	98
Acartia copepodites	16286	15876	97	6574	6432	98
Acartia tonsa	4742	4552	96	3899	3751	96
Others	2330	2207	-	2244	2213	-
Total (excluding cirriped nauplii)	42083	41147	98	18934	18535	98
Dye specific species	21685	21050	97	11206	10914	97
September 13-14						
Polychaete larvae	5303	5275	99	2626	2596	99
Copepod nauplii	564	553	98	665	654	100
Cirriped nauplii	1116	1067	96	2096	2054	98
Acartia copepodite	7469	7396	99	3500	3431	98
Acartia tonsa	722	698	97	837	800	96
Others	2870	2802	-	2135	2090	-
Total (excluding cirriped nauplii)	14058	13922	99	7628	7481	98
Dye specific species	8856	8747	99	5056	4948	98

Table C.2-2. Mean densities, relative abundance, and survival statistics for major zooplankton groups collected at intake (IN) and discharge (DC) stations during entrainment studies at Calvert Cliffs Nuclear Power Plant in 1978 (from Ref. 1).

		Jun 13	Jul 11	Jul 13	Aug 8	Aug 10	Sep 12
Copepod nauplii							
N/m^3	IN	3430	5981	18055	11809	33006	17948
	DC	698	2337	5849	3810	7726	4588
% of Total (minus cirriped)	IN	15.9	69.7	56.5	44.0	68.6	50.8
	DC	6.2	53.5	43.9	24.5	45.1	34.3
% Alive	IN	99	99	99	98	97	99
	DC	91	97	99	92	89	97
% Survival		18.6	38.4	32.1	30.4	21.5	23.1
***Acartia* copepodites**							
N/m^3	IN	5908	1220	9397	6865	10043	13041
	DC	1197	623	4338	3763	3870	3842
% of Total (minus cirriped)	IN	27.3	14.2	29.4	25.6	20.9	36.9
	DC	10.7	14.3	32.5	24.2	22.6	28.7
% Alive	IN	96	98	99	91	95	95
	DC	85	98	98	77	94	90
% Survival		17.9	49.8	45.4	46.4	38.2	28.0
***Acartia tonsa* adults**							
N/m^3	IN	2960	84	1212	3045	2070	945
	DC	1105	92	840	2897	2233	619
% of Total (minus cirriped)	IN	13.7	1.0	3.8	11.3	4.3	2.7
	DC	9.9	2.1	6.3	18.6	13.0	4.6
% Alive	IN	93	95	98	62	73	68
	DC	77	93	92	57	70	58
% Survival		30.9	>100	64.8	88.3	>100	55.3
Annelida							
N/m^3	IN	1105	266	1231	2450	799	1480
	DC	665	217	951	2301	811	2078
% of Total (minus cirriped)	IN	5.1	3.1	3.9	9.1	1.7	4.2
	DC	6.0	5.0	7.1	14.8	4.7	15.5
% Alive	IN	99	100	100	100	100	100
	DC	100	100	99	99	99	98
% Survival		60.3	81.4	76.7	93.3	>100	>100
Other species							
N/m^3	IN	8215	1026	2033	2698	2183	1947
	DC	7511	1098	1358	2781	2503	2267
% of Total (minus cirriped)	IN	38.0	12.0	6.4	10.0	4.5	5.4
	DC	67.2	25.1	10.2	17.9	14.6	16.9
Cirriped nauplii							
N/m^3	IN	1015	1328	2989	509	167	4074
	DC	2789	2868	4375	599	249	4983
% Alive	IN	96	96	98	87	87	93
	DC	97	98	98	93	98	94
% Survival		>100	>100	>100	>100	>100	>100
Total minus cirriped nauplii							
N/m^3	IN	21618	8577	31928	26867	48101	35361
	DC	11176	4367	13336	15552	17143	13394

Table C.2-3. Mean densities, relative abundance, and survival statistics for major zooplankton groups collected at intake (IN) and Discharge (DC) stations during entrainment studies at Calvert Cliffs Nuclear Power Plant in 1979 (from Ref. 172).

		Jun 5	Jul 10	Jul 12	Aug 14	Aug 16	Sept 13
Copepod nauplii							
N/m^3	IN	2506	14498	44758	21452	53076	30213
	DC	682	3394	9330	3370	29962	6534
% of Total (minus cirriped)	IN	9.6	29.6	60.7	59.4	64.3	54.2
	DC	2.5	15.8	42.9	42.0	56.4	43.3
% Alive	IN	99.6	99.9	99.6	98.5	99.8	99.0
	DC	99.5	99.2	98.9	98.2	98.4	97.9
% Survival		24.6	22.3	20.3	16.2	43.1	23.2
Acartia copepodites							
N/m^3	IN	2272	22709	16538	10436	29738	19378
	DC	575	6388	4081	2244	12025	5584
% of Total (minus cirriped)	IN	7.8	46.4	22.4	29.0	27.1	34.8
	DC	2.1	29.8	18.8	28.0	22.6	37.0
% Alive	IN	93.4	99.7	98.5	96.2	96.9	99.3
	DC	98.5	92.1	95.6	94.2	95.0	94.3
% Survival		23.0	25.2	24.9	20.5	40.4	27.6
Acartia tonsa adults							
N/m^3	IN	*	3537	2922	1083	3816	1695
	DC	*	2719	2052	502	3017	1508
% of Total (minus cirriped)	IN	*	7.2	4.0	3.0	3.5	3.0
	DC	*	12.7	9.4	7.5	9.4	10.0
% Alive	IN	*	79.3	78.1	85.3	84.6	85.5
	DC	*	52.0	63.1	65.2	77.5	63.4
% Survival		*	27.5	56.1	40.1	>100	62.5
Annelida							
N/m^3	IN	1534	397	917	557	733	470
	DC	362	554	468	358	596	301
% of Total (minus cirriped)	IN	5.3	1.8	1.2	1.5	0.7	0.8
	DC	1.2	2.6	2.2	4.5	1.1	2.0
% Alive	IN	99.5	100.0	98.2	99.9	100.0	100.0
	DC	99.7	99.8	99.4	99.4	99.9	98.9
% Survival		43.6	63.7	53.1	71.2	>100	81.4
Other species							
N/m^3	IN	22950	7332	8581	2519	4557	3972
	DC	22085	8393	5825	1455	5443	1156
% of Total (minus cirriped)	IN	78.4	15.0	11.6	7.0	4.3	0.7
	DC	92.2	39.1	21.9	18.1	10.2	7.7
Cirriped nauplii							
N/m^3	IN	5328	5294	5125	859	1002	1299
	DC	12302	28779	21347	1009	3136	2194
% Alive	IN	94.2	97.2	94.5	92.4	97.3	90.7
	DC	99.1	98.9	99.2	92.5	97.0	91.1
% Survival		>100	>100	>100	>100	>100	>100
Total minus cirriped nauplii							
N/m^3	IN	29292	48973	73715	36097	105920	55729
	DC	27204	21448	21756	3029	53143	15083

*Insufficient data to analyze

Table C.2-4. Survival statistics for several zooplankton groups sampled during entrainment studies at Calvert Cliffs Nuclear Power Plant in 1977 and 1978. Percent survival is defined by (# alive at DC/# alive at IN) x 100. Percent survival is not defined for the case in which # alive at DC ≥ alive at IN; i.e., percent survival ≥ 100 (from Ref. 1).

I.	% Survival (95% C.I.):	6/26/77	6/13/78	
	Copepod nauplii	71 (63-75)	18.6 (14.9-22.3)	
	Acartia copepodites	68 (60-75)	17.9 (15.3-20.5)	
	Acartia tonsa adults	-	30.9 (25.3-36.5)	
	Annelida	87 (78-96)	60.3 (48.3-72.3)	
	All dye-sensitive spp.	72 (66-79)	31.2 (28.1-34.3)	
II.	% Survival (95% C.I.):	7/12/77	7/11/78	7/13/78
	Copepod nauplii	78 (56-95)	38.4 (31.9-44.9)	32.1 (30.1-34.1)
	Acartia copepodites	64 (52-74)	49.8 (41.6-58.0)	45.4 (40.3-50.5)
	Acartia tonsa adults	≥100 -	≥100 -	64.8 (50.9-78.7)
	Annelida	≥100 -	81.4 (70.6-92.2)	76.7 (64.8-88.6)
	All dye-sensitive spp.	74 (58-85)	58.2 (50.0-66.4)	50.8 (46.1-55.5)
III.	% Survival (95% C.I.):	8/9/77	8/8/78	8/10/78
	Copepod nauplii	38 (36-45)	30.4 (25.2-35.6)	21.5 (19.0-24.0)
	Acartia copepodites	41 (36-45)	46.4 (38.2-54.6)	38.2 (32.7-43.7)
	Acartia tonsa adults	82 (67-87)	88.3 (70.2-100)	≥100 -
	Annelida	≥100 -	93.3 (73.4-100)	≥100 -
	All dye-sensitive spp.	52 (47-57)	64.6 (57.2-72.0)	50.2 (44.1-56.3)
IV.	% Survival (95% C.I.):	9/13/77	9/12/78	
	Copepod nauplii	49 (43-59)	25.1 (22.3-27.9)	
	Acartia copepodite	46 (42-55)	28.0 (25.1-30.9)	
	Acartia tonsa adults	≥100 -	55.3 (36.3-74.3)	
	Annelida	≥100 -	≥100 -	
	All dye-sensitive spp.	57 (51-66)	40.4 (36.7-44.1)	

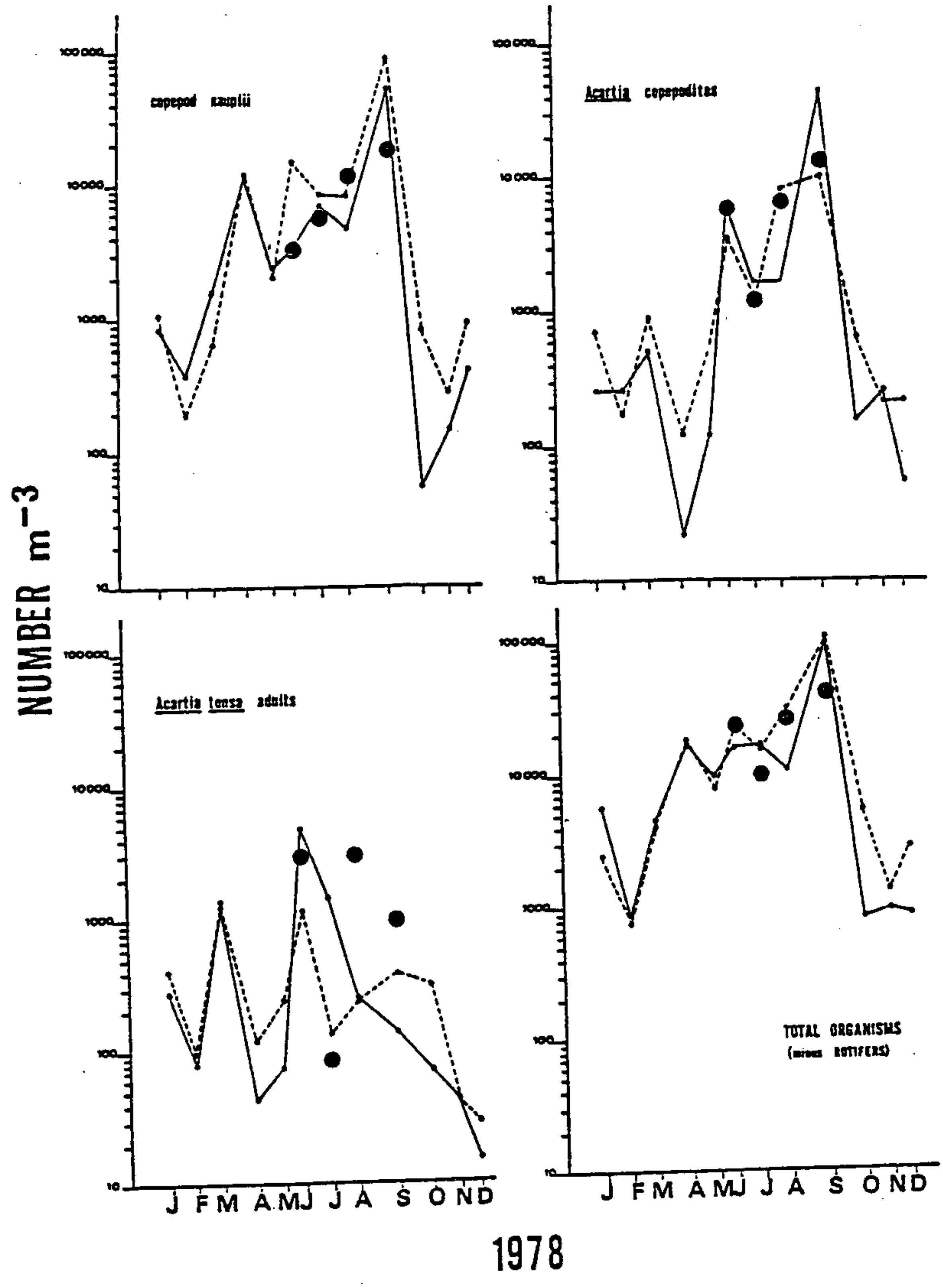

Figure C.2-1. Densities of entrained zooplankton (●) compared with densities of nearfield zooplankton (—— plant site; ---- reference station). Entrainment densities are numbers averaged over a 24-hr period, and nearfield densities are numbers averaged for surface, middle, and bottom depths at each station (from Ref. 1).

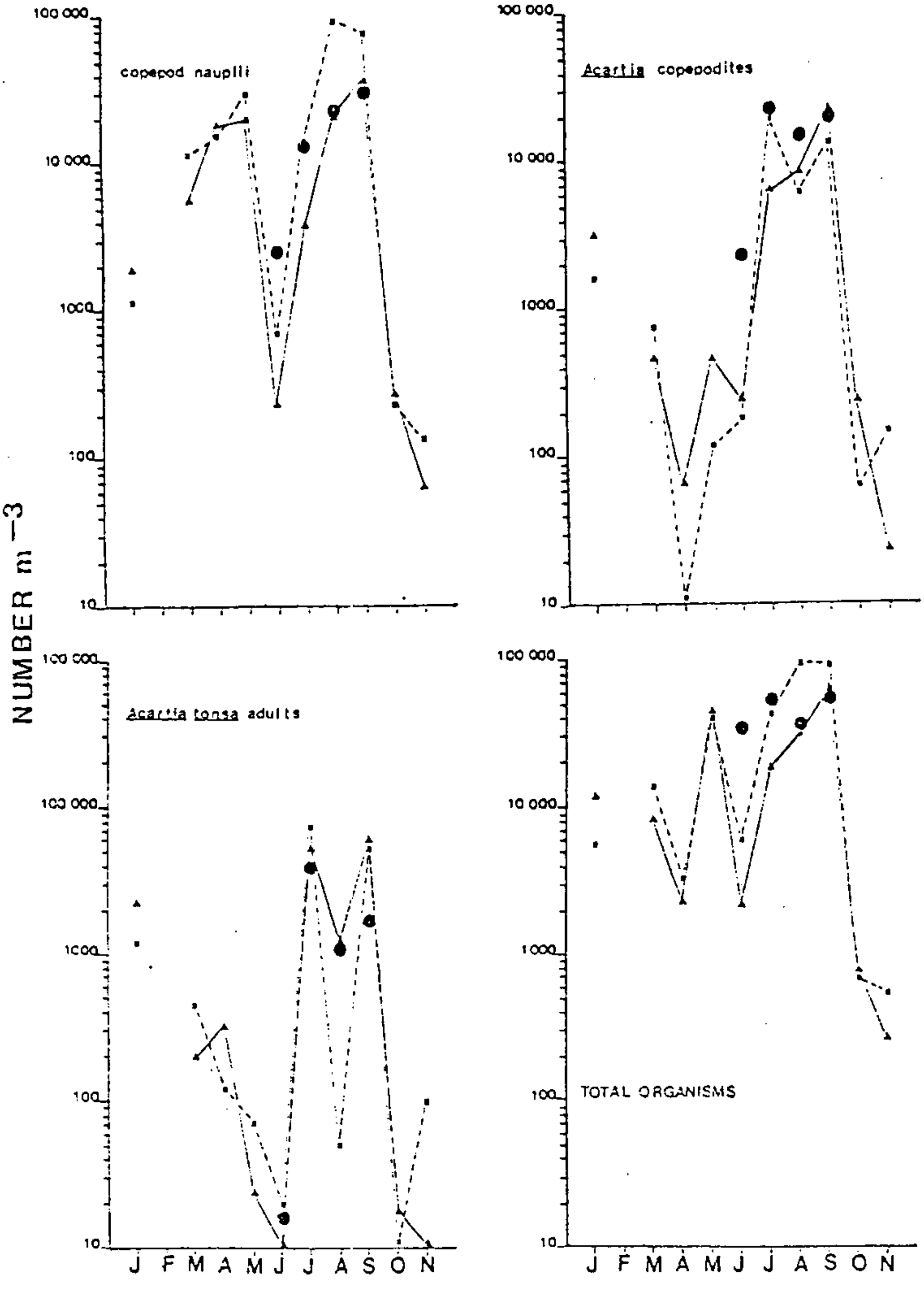

Figure C.2-2. Densities of entrained zooplankton (●) at Unit 2, Calvert Cliffs Nuclear Power Plant, 1979, compared with densities of Chesapeake Bay, nearfield zooplankton (▲— plant site; ■- - reference station at Kenwood Beach). Entrained densities are numbers averaged over a 24-hr period. Nighttime nearfield densities are averages of single samples from surface, middle, and bottom depths at each station (from Ref. 172).

APPENDIX C.3. - BARNACLE LARVAE PRODUCTION IN DISCHARGE CONDUITS (MMC)

C.3.1. Objective

To evaluate whether the reproductive potential of barnacles lining the discharge conduits could account for increases in barnacle larvae observed at the discharge site (observed in ANSP entrainment studies).

C.3.2. Data Sources

Refs. 41, 42, 103, 104.

C.3.3. Study History

Calculations conducted for this evaluation were applied to spring 1976 zooplankton entrainment data.

C.3.4. Sampling Methods

Not applicable.

C.3.5. Analysis

Estimation of the surface area occupied by individual barnacles and knowledge of the surface area of each conduit yielded an estimate for the maximum number of barnacles in each conduit. These data and information on fecundity were then used to provide estimates of barnacle nauplii produced in discharge conduits.

C.3.6. Results

- The following information was obtained for *Balanus eburneus* and *Balanus improvisus*, two barnacle species that were found in the Calvert Cliffs area:

	Basal Diameter	Surface Area Occupied by One Individual	Maximum Number of Barnacles in Each Conduit (assuming a single layer)
B. eburneus	25 mm	4.9×10^{-4} m^2	1.9×10^7
B. improvisus	13 mm	1.3×10^{-4} m^2	7.1×10^7

The surface area of the interior walls of each discharge conduit is 9,368 m^2. B. improvisus fecundity appears to be at least 400 nauplii per brood from a single adult, with larger individuals releasing up to 18,000 larvae per brood. Furthermore, this species may produce more than one brood per year; up to 3 broods per year are possible under constant light conditions and proper food supply (Ref. 103). B. eburneus, because of its larger size, would be expected to produce even greater numbers of offspring.

- Table C.3-1 presents data that demonstrate the extent to which barnacle nauplii produced in the discharge structures could increase density estimates taken at the discharge location. Fecundity values of 1,000 to 20,000 per adult were used as a good estimate of the anticipated annual reproductive rates of resident Chesapeake Bay barnacle populations. Release times were calculated for a range of 1 hour to 28 days. When the greatest fecundity rates for each species are used, barnacles in the conduits could produce from 5,600-20,000 larvae/m^3 of water in one month.

- These calculations are supported somewhat by the findings of Cory (1967, Ref. 104) who placed 1-cm^2 substrates in the Patuxent River and counted the number of settling barnacles. Although the numbers were extremely high after only one month, an average of 570 mature individuals per cm^2 were present after three months. This value, extrapolated to the area of a single conduit, resulted in a projected 5.3×10^8 barnacles, a figure somewhat larger than the estimate of 7.1×10^7 barnacles presented here.

C.3.7. Significance and Critique of Findings

It seems likely that the increase in barnacle larvae densities at the discharge site during certain times of the year is a result of production of nauplii within the discharge conduits. If barnacles are multilayered within conduits, total fecundity would be considerably greater; however, if the larger of the two species were present, lower fecundity estimates would result.

Table C.3-1. Estimates of the potential density (numbers/m^3) of barnacle nauplii produced in discharge conduits.

	Balanus eburneus	Balanus improvisus
Total number of barnacles in conduit	1.9×10^7	7.1×10^7
	(Assume 28 m^3/s flow)	
Fecundity: 1000/adult		
Release Time:		
1 hr	1.9×10^5	2.3×10^5
3 hr	6.3×10^4	2.3×10^5
10 hr	1.8×10^4	7.0×10^4
24 hr	7.8×10^3	2.9×10^4
7 days	1.1×10^3	4.2×10^3
28 days	0.3×10^3	1.0×10^3
Fecuncity: 10,000/adult		
Release Time:		
1 hr	1.9×10^6	7.0×10^6
3 hr	6.3×10^5	2.3×10^6
10 hr	1.8×10^5	7.0×10^5
24 hr	7.8×10^4	2.9×10^5
7 days	1.1×10^4	4.2×10^4
28 days	2.8×10^3	1.0×10^4
Fecundity: 20,000/adult		
Release Time:		
1 hr	3.8×10^6	14.0×10^6
3 hr	12.6×10^5	4.6×10^6
10 hr	3.6×10^5	14.0×10^5
24 hr	15.6×10^4	5.8×10^5
7 days	2.2×10^4	8.4×10^4
28 days	5.6×10^3	2.0×10^4

APPENDIX C.4. - ZOOPLANKTON ENTRAINMENT STUDY

(UMBC, MMC)

C.4.1. Objective

To determine whether decreases in zooplankton density that apparently are a result of plant passage actually are due to errors in sampling methodology.

C.4.2. Data Sources

Ref. 113, 174.

C.4.3. Study History

Study conducted during July and August 1978 and July 1979.

C.4.4. Sampling Methods

- Samples were pumped over 24-hour periods at intake and discharge locations using diaphragm and Flygt pumps.
- In the 1978 studies, triplicate sampling was conducted at three intake locations with the Flygt pump and at one location with the diaphragm pump.
- In 1979, only one intake location was sampled with two diaphragm pumps.
- Samples were filtered through 35- or 75-μm-mesh netting, preserved, counted, and identified in the laboratory.

C.4.5. Analysis

Univariate parametric analyses were employed for various comparisons:

- Densities were log-transformed and variances were analyzed among sites (intake and discharge), stations (locations across the intake), and runs (time). Horizontal patchiness across the intake area was analyzed using variance among intake stations within runs as the criterion.
- Pump efficiency was compared by analyzing variance of density estimates made by the same pump type at the different sites and by correlating density estimates obtained by the different pump types at each site.

- An ANOVA was applied to July 1979 data using oriface velocity (pump speed) and run (time) as factors.

C.4.6. Results

- Sampling efficiency of diaphragm (low volume) and Flygt (high volume) pumps appeared similar in experiments conducted in slow-moving creek water.

- Densities estimated from Flygt pump samples differed between runs and between sites within runs in both July and August 1978 (Table C.4-1).

- Efficiency of Flygt and diaphragm pumps was similar at intake locations. Increasing the volume of the sample did not alter density estimates (Table C.4-2; Figs. C.4-1, C.4-2).

- Flygt pumps captured significantly lower numbers of zooplankton than did diaphragm pumps at the discharge location. However, densities in discharge samples obtained with the diaphragm pump were still generally significantly less than for comparable samples taken at the intake area (Table C.4-2; Figs. C.4-1, C.4-2).

- In July 1978, the variability associated with sampling at different locations across the intake embayment generally was not significantly different from the variability between the replicates at any one intake location (Table C.4-1). The August 1978 data, however, only supported this finding for copepod adults, but found significant station variability for copepodids and nauplii. This finding suggests that sampling at one intake location may or may not be sufficient.

- After examining material retained on 35-μm-mesh netting, it was concluded that there was only a slight increase in zooplankton "fragments" collected at the discharge locations over those in samples at intake locations.

C.4.7. Significance and Critique of Findings

- Diaphragm and Flygt pumps both provide accurate zooplankton density estimates when sampling in still- and slow-moving waters (intake area).

- Neither pump type may be adequate for sampling in rapid flow velocities such as those at the discharge location. Although discharge samples from both types of pumps yielded significantly lower numbers than did comparable intake samples, the diaphragm pump collected higher densities than the Flygt pump.

- In July 1978, the accuracy of estimating zooplankton densities entering the plant was not improved by increasing the number of sampling locations. Results indicate that one sampling location at the intake may be sufficient and suggest that intake densities reported in other entrainment studies may be reasonably accurate estimates of true intake densities.

- The relationship between orifice velocity of the pump relative to the velocity of the flow past the pump may be an important consideration for obtaining accurate density estimates. This relationship was investigated for the diaphragm pump in summer 1979 field experiments, results of which were inconclusive (Table C.4-3). If this were an important factor, the Flygt pump, which had a lower orifice velocity (despite its higher volume capacity) than did the diaphragm pump, would underestimate density to a greater extent in high flow velocities. This factor is being considered in a follow-up PPSP-sponsored study.

- The hypothesis that mechanical damage is responsible for density losses experienced through entrainment at Calvert Cliffs could not be strongly supported since there was little observable increase in zooplankton "fragments" between intake and discharge locations.

Table C.4-1. Summary of analyses of variance of densities of copepod life stages in July and August 1978. Flygt (submersible pump) log-transformed data (from Ref. 174).

July 1978		Mean Squares			
Source	d.f.	Adults	Copepodites	Nauplii	Harpacticoids
Run	11	2.30**	2.28**	0.93**	2.22**
Site/Run	12	2.57**	5.61**	7.93**	0.36**
Sta/Site/Run	24	0.54	0.09	0.12	0.73**
Within	96	0.38	0.17	0.15	0.15

** P <.01

August 1978		Mean Squares			
Source	d.f.	Adults	Copepodites	Nauplii	Harpacticoids
Run	11	4.14**	1.51**	0.62**	3.25**
Site/Run	12	1.55**	0.26**	5.49**	1.39**
Sta/Site/Run	24	0.34	0.21**	0.11**	1.35**
Within	96	0.28	0.04	0.05	0.58

** P <.01

Adults and copepodites were Acartia tonsa.

Note: Nauplii included all species. Harpacticoids were adults and copepodites.

Table C.4-2. Comparisons between pumps and between intake and discharge samples (average densities per m^3, with standard deviations over all runs) for calanoid copepod life stages. Nauplii may include other species (from Ref. 174).

July, 1978

Pump	Intake			Discharge		
	Adults	Copepodites	Nauplii	Adults	Copepodites	Nauplii
Diaphragm	1290 ±608 +	4007 ±2019 ++	28226 ±7231 ++	730 ±492	1470 ±736 *	12378 ±8159 *
Submersible (Flygt)	895 ±628 +	2765 ±1490 ++	29665 ±9773 ++	426 ±414	587 ±524	2478 ±2587

August, 1978

Pump	Intake			Discharge		
	Adults	Copepodites	Nauplii	Adults	Copepodites	Nauplii
Diaphragm	5981 ±2086 *	19567 ±5077 ++	73366 ±31163	5278 ±1419 **	13886 ±4957	52811 ±22699 *
Submersible (Flygt)	3568 ±2632	21757 ±12639 +	80391 ±35980 ++	3331 ±2418	13740 ±4368	28393 ±14010

Vertical Comparisons-- * P <.05, significantly greater than other pump, ** P <.01

Horizontal Comparisons -- + P <.05, significantly greater than other site, ++ P <.01

Table C.4-3. Summary of analyses of variance of copepod life stages in July 1979 (diaphragm pump) at three different pump speeds. Log-transformed data (from Ref. 174).

		Mean Square			
Source	d.f.	Adults	Copepodites	Nauplii	Harpacticoids
Run	3	3.89*	2.33**	6.22**	0.66**
Speeds/Run	8	0.69	0.17	0.02*	0.01
Within	13	0.69	0.36	0.01	0.03

* $P < .05$ ** $P < .01$

Note: Adults and copepodites were *Acartia tonsa*. Nauplii included other species. Harpacticoids were adults and copepodites.